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June 15, 1981

BDM/M-TR-0013-81

DARPA ADVANCED CANNON PROPELLANT (ACP)
LIBRARY USER'S GUIDE
APPENDIX E
PATENTS DEALING WITH LP GUN HARDWARE

ARPA Order Number: 4105
Contractor: The BDM Corporation, McLean, Virginia
Effective Date of Contract: January 14, 1981
Contract Expiration Date: January 29, 1982
Reporting Period: February 11, 1981 through June 30, 1981
Contract Number: MDA903-81-C-0025
Principal Investigator: Dr. Terrence P. Goddard
The BDM Corporation
P.O. Box 2019
Monterey, California 93940
Phone (408) 649-3880
Short Title of Work: ACP Library

FOREWORD

This Appendix is a compilation of patents that deal with liquid (or fluid) propellant gun hardware, including complete gun designs, valving, pumping and sealing components, and ignition devices. No claim is made on the utility of any of the devices described herein, and this volume is intended for reference purposes only.

Two research groups have made substantial contributions in recent years to the patent literature on LP guns -- GE and Pulsepower Systems. These patents are arranged separately from the remainder.

PATENTS ASSIGNED TO THE GENERAL ELECTRIC COMPANY

Patent Number: 3,763,739
Author: Douglas Pray Tassie, St. George, VT
Title: High Rate of Flow Port for Spool Valves
Date: October 9, 1973

Patent Number: 3,782,241
Author: Eugene Ashley, Burlington, VT
Title: Zero Ullage Injection Valve
Date: January 1, 1974

Patent Number: 3,783,737
Author: Eugene Ashley, Burlington, VT
Title: SEAL
Date: January 8, 1974

Patent Number: 4,011,817
Author: Eugene Ashley, Burlington, VT
Title: Liquid Propellant Weapon System
Date: March 15, 1977

Patent Number: 4,023,463
Author: Douglas Pray Tassie, Williston, VG
Title: Liquid Propellant Gun (Check Valve and Damper)
Date: May 17, 1977

Patent Number: 4,043,248
Author: Melvin John Bulman, Shelburne, VT; Alfred Rapp Graham, Burnt Hills, VT
Title: Liquid Propellant Gun (Recoilless Regenerative Piston)
Date: August 23, 1977

Patent Number: 4,050,348
Author: Alfred Rapp Graham, Burnt Hills, VT
Title: Liquid Propellant Gun (Controlled Leakage Regenerative Piston)
Date: September 27, 1977

Patent Number: 4,050,349
Author: Alfred Rapp Graham, Burnt Hills, NY
Title: Liquid Propellant Gun (Scaling with Multiple Combustion Assemblies)
Date: September 27, 1977

Patent Number: 4,050,352
Author: Douglas Pray Tassie, St. George, VT
Title: Renewable Liquid Investment Seal
Date: September 27, 1977

PATENTS ASSIGNED TO THE GENERAL ELECTRIC COMPANY (Continued)

Patent Number: 4,051,762
Author: Eugene Ashley, Burlington, VT
Title: Liquid Propellant Weapon System
Date: October 4, 1977

Patent Number: 4,063,486
Author: Eugene Ashley, Burlington, VT
Title: Liquid Propellant Weapon System
Date: December 20, 1977

Patent Number: 4,069,739
Author: Eugene Ashley, Burlington, VT
Title: Liquid Propellant Weapon Systems
Date: January 24, 1978

Patent Number: 4,085,653
Author: Douglas Pray Tassie, St. George, VT; Robert A. Pustell, Andover, Mass.
Title: Ignition Device
Date: April 25, 1978

Patent Number: 4,102,269
Author: Eugene Ashley, Burlington, VT
Title: Liquid Propellant Weapon System
Date: July 25, 1978

Patent Number: 4,126,078
Author: Eugene Ashley, Burlington, VT
Title: Liquid Propellant Weapon System
Date: November 21, 1978

Patent Number: 4,132,149
Author: Eugene Ashley, Burlington, VT
Title: Liquid Propellant Weapon System
Date: January 2, 1979

Patent Number: 4,193,335
Author: Douglas P. Tassie, St. George, VT
Title: Gun Misfire Control
Date: March 18, 1980

Patent Number: 4,215,620
Author: Douglas P. Tassie, St. George, VT; Robert A. Putsell, Andover, Mass.
Title: Ignition Device
Date: August 5, 1980

PATENTS ASSIGNED TO THE GENERAL ELECTRIC COMPANY (Continued)

Patent Number: 4,231,282
Author: Eugene Ashley, Burlington, VT
Title: Ignition System
Date: November 4, 1980

United States Patent [19]

Tassie

[11] **3,763,739**

[45] **Oct. 9, 1973**

[54] **HIGH RATE OF FLOW PORT FOR SPOOL VALVES**

[75] Inventor: **Douglas Pray Tassie**, St. George, Vt.

[73] Assignee: General Electric Company, Burlington, Vt.

[22] Filed: **June 1, 1971**

[21] Appl. No.: **148,833**

[52] U.S. Cl. .... 89/7, 89/1 R, 137/625.3
[51] Int. Cl. F41f 1/04
[58] Field of Search 89/7, 8; 137/625.3

[56] **References Cited**

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2,483,719	10/1949	Anderson	137/625.3 X
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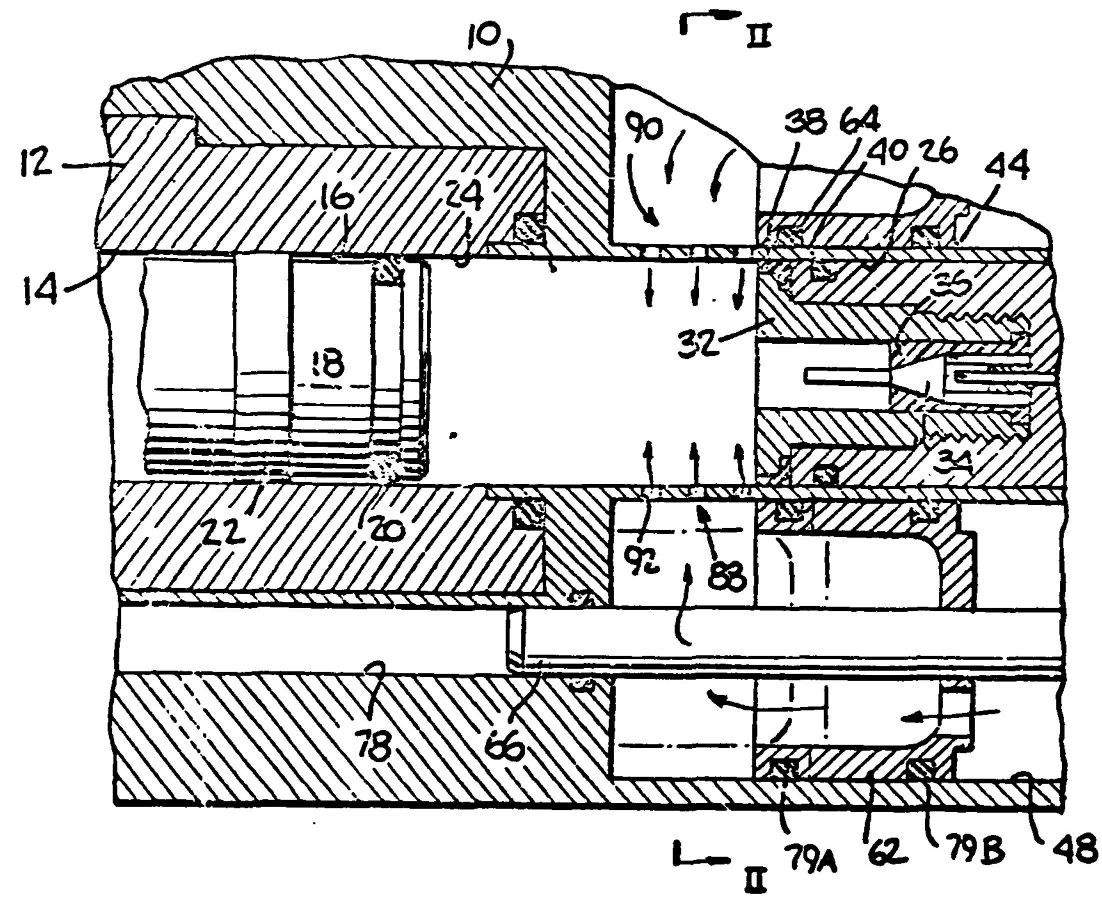
3,138,990	6/1964	Jukes et al.	89/7
2,981,153	4/1961	Wilson, Jr. et al.	89/7
3,046,737	7/1962	Ottestad	89/7
3,455,202	7/1969	Dilon et al.	89/7

Primary Examiner—Samuel W. Engle
Attorney—Bailin L. Kuch, Irving M. Freedman, Harry C. Burgess, Frank L. Neuhauser, Oscar B. Waddell and Joseph B. Forman

[57] **ABSTRACT**

A feature of this invention is a spool valve which has a spool with an O-ring seal, said seal having a given longitudinal dimension, the spool operating in a bore in a housing to open and close a port opening into said bore, said port formed of a plurality of apertures, each aperture having a diameter, parallel to the longitudinal axis of said O-ring, which is smaller than said given longitudinal dimension of said seal.

2 Claims, 5 Drawing Figures



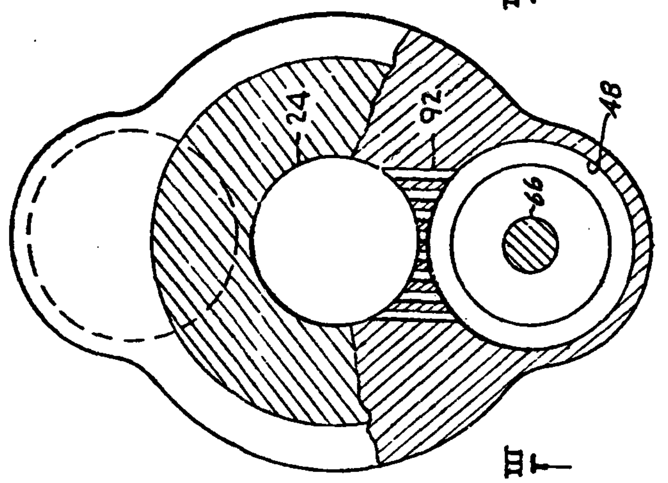


Fig. 2.

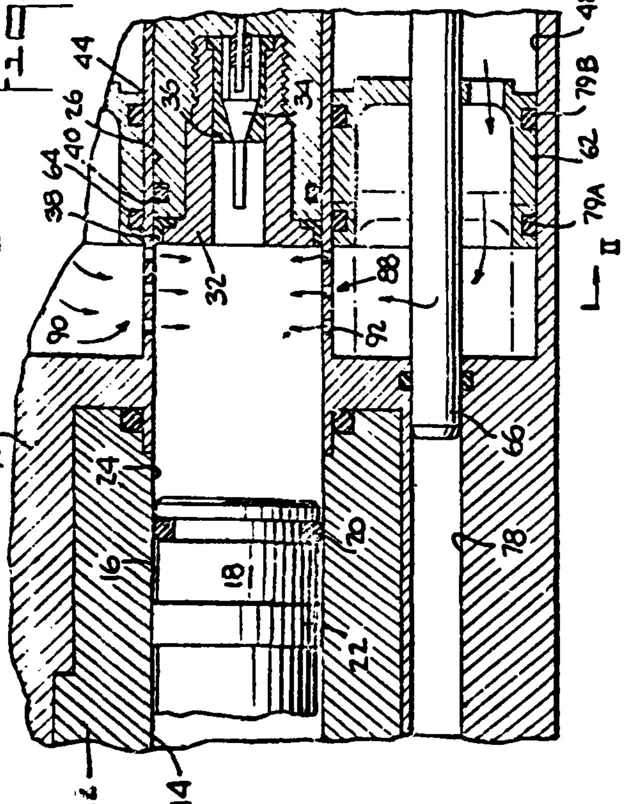


Fig. 1.

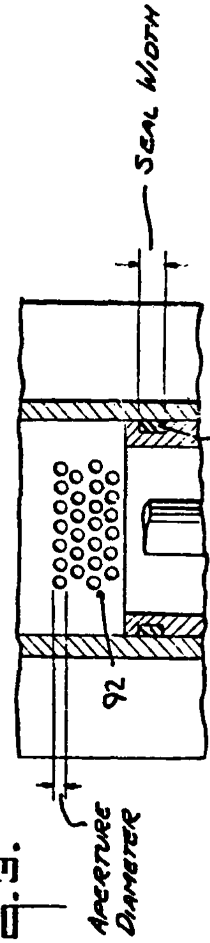
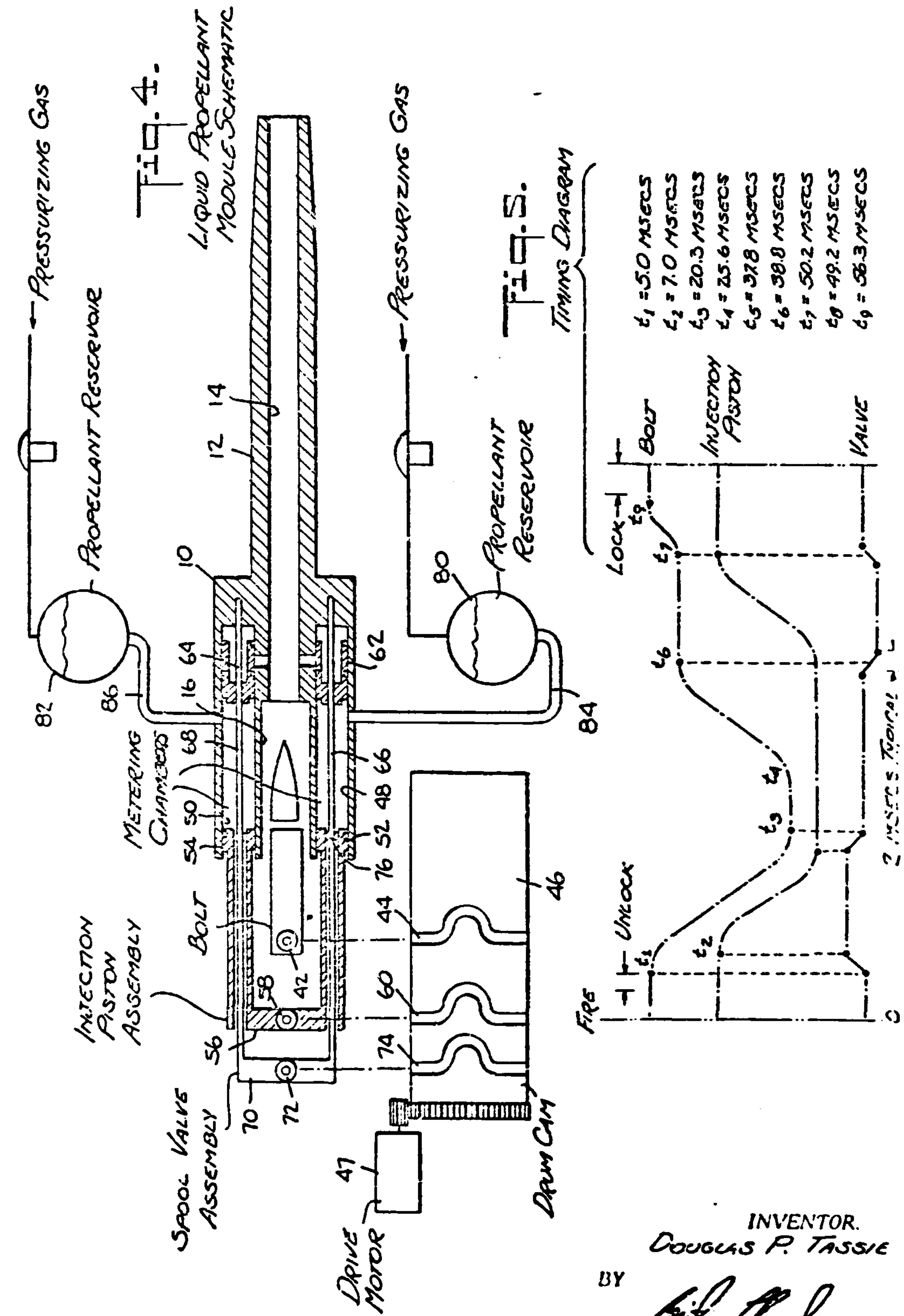


Fig. 3.

INVENTOR
DOUGLAS P. TASSIE

BY

ATTORNEY



INVENTOR.
DOUGLAS P. TASSIE

BY

ATTORNEY

HIGH RATE OF FLOW PORT FOR SPOOL VALVES

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates to high rate of flow, rapid actuation valves, such as spool valves, and is particularly adapted for high rate of fire, liquid propellant guns. The invention herein described was made in the course of or under a contract or subcontract thereunder with the Department of the Navy.

2. Prior Art

Low rate of fire, liquid propellant or initiant guns are disclosed in U.S. Pat. No. 3,455,202 issued July 15, 1969 to Dixon et al., utilizing a quasi-spool valve; and U.S. Pat. No. 3,537,352 issued Nov. 3, 1970 to R. W. Joyce, utilizing a ball valve.

SUMMARY OF THE INVENTION

To achieve a high rate of fire in a liquid propellant gun, the propellant must be injected into the combustion chamber in a short interval of time. This requires high rate of flow of the propellant through the valve controlling the combustion chamber, and a rapid on/off actuation of the valve. A high rate of flow, at a given pressure, requires a large cross-section of conduit. Spool valves are conventionally utilized to provide rapid actuation. An efficient form of the conventional spool valve utilizes O-ring seals. O-ring seals are rapidly damaged when they are passed over an opening which is larger than the longitudinal dimension, i.e., width, of the seal.

Accordingly, it is an object of this invention to provide a spool valve with a port which provides adequate support for the seal while permitting a high rate of flow.

An additional object of this invention is to provide a spool valve with a port which controls the rise and fall characteristics of the pulse envelope of the fluid flow.

A feature of this invention is a spool valve having a spool with an O-ring seal, said seal having a given longitudinal dimension, the spool operating in a bore in a housing to open and close a port opening into said bore, said port formed of a plurality of apertures, each aperture having a diameter, parallel to the longitudinal axis of said O-ring, which is smaller than said given longitudinal dimension of said seal.

BRIEF DESCRIPTION OF THE DRAWING

These and other objects, advantages and features of the invention will be apparent from the following specification thereof taken in conjunction with the accompanying drawings in which:

FIG. 1 is a partial view, in cross-section, taken on a longitudinal plane, through a liquid propellant gun incorporating a spool valve embodying this invention;

FIG. 2 is a transverse view, in partial cross-section, taken along the plane II—II of FIG. 1;

FIG. 3 is a detail view, in cross-section, taken along the plane III—III of FIG. 2;

FIG. 4 is a schematic of the gun of FIG. 1; and

FIG. 5 is a timing diagram of the operation of the gun of FIG. 4.

DESCRIPTION OF THE PREFERRED EMBODIMENT

The gun includes a receiver 10, in which is fixed a barrel 12 having a bore 14. The aft end of the bore is chambered at 16 to receive a projectile 18 having an O-ring seal 20 and a rifling band 22, and to provide a combustion chamber 24. The receiver includes a bolt body 30 having a bolt head 32 having a central bore in which an electrode 34 is fixed in a dielectric sleeve 36. An L-seal 38 is provided at the extreme forward end as a high pressure firing seal, and an O-ring 40 is provided aft of the L-seal as a low-pressure back up seal against fluid leakage during propellant injection. The bolt has a transversely projecting roller 42 which rides in a cam slot 44 in a cam 46, driven by a motor 47.

The receiver includes two additional longitudinal bores 48 and 50 in which two pistons 52 and 54 respectively slide. The two pistons are coupled aft by a yoke 56 which has a transversely projecting roller 58 which rides in a cam slot 60 in the cam 46.

Two spools 62 and 64 respectively slide in the forward portions of the bores 48 and 50. The spools are respectively fixed to rods 66 and 68 which are coupled aft by a yoke 70 which has a transversely projecting roller 72 which rides in a cam slot 74 in the cam 46. Each rod is journalled through a bore 76 in the piston and a bore 78 in the receiver. Each spool has a forward O-ring seal 79A and an aft O-ring seal 79B.

Two propellant reservoirs 80, 82 are pressurized by suitable supplies of gas and are respectively coupled by conduits 84, 86 to the bores 48, 50.

Two ports 88, 90 are povided respectively between the bore 48 and the combustion chamber 24 and the bore 50 and the combustion chamber. Each port consists of a plurality of bores 92, each bore having a diameter which is smaller than the longitudinal width of the O-ring seal 79A, 79B. Thus the annulus around each bore supports the seal as the seal moves over the bore. The total cross-sectional area of each port 88, 90 is equal to the sum of the cross-sectional areas of the component bores 92. The pattern of holes may be arranged to provide either a steep or shallow a rise and fall of the fluid pulse envelope as is desired. For example, if it is desired to have as steep a rise as possible, the number of bores in the first rows of bores which are uncovered by the spool is made as large as possible, but if it is desired to have a shallow fall, the number of bores in the last rows of bores which are covered by the spool is progressively made smaller.

The timing of the gun is illustrated in FIG. 5.

It is contemplated that the inventive concepts hereinabove described may be variously otherwise embodied and combined without departing from the inventive principles involved and intended to be covered by the appended claims, except insofar as limited by the prior art.

What is claimed is:

1. A gun comprising:

a conduit for passing a fluid;

a valve coupled to said conduit for controlling the passage of the fluid therethrough;

said valve including:

a valve chamber having a surface having a port means for fluid therein,

a valve spool having a ring type seal abuting said surface for closing and for exposing said port means, said valve spool disposed for movement along an axis,

said ring type seal having a cross-section diameter parallel to said axis,

said port means comprising a plurality of apertures, each having a respective diameter parallel to said

axis which is smaller than said cross section diameter of said ring type seal,

said plurality of apertures being arranged in a pattern of acceleration of cross-sectional port area such that as said valve spool moves at a constant velocity to open said port, an increasing cross-sectional port area is exposed per unit time.

2. A gun comprising:

a conduit for passing a fluid;

a valve coupled to said conduit for controlling the passage of the fluid therethrough;

said valve including:

a valve chamber having a surface having a port means for fluid therein,

a valve spool having a ring type seal abuting said surface for closing and for exposing said port means, said valve spool disposed for movement along an axis,

said ring type seal having a cross-section diameter parallel to said axis,

said port means comprising a plurality of apertures, each having a respective diameter parallel to said axis which is smaller than said cross-section diameter of said ring type seal,

said plurality of apertures being arranged in a pattern of deceleration of cross-sectional port area such that as said valve spool moves at a constant velocity to close said port, a decreasing cross-sectional port area is closed per unit time.

* * * * *

United States Patent [19]

Ashley

[11] 3,782,241

[45] Jan. 1, 1974

[54] ZERO ULLAGE INJECTION VALVE

[75] Inventor: Eugene Ashley, Burlington, Vt.

[73] Assignee: General Electric Company, Burlington, Vt.

[22] Filed: Oct. 28, 1971

[21] Appl. No.: 193,351

[52] U.S. Cl. 89/7, 137/509
[51] Int. Cl. F41j 1/04
[58] Field of Search 89/7; 137/509; 417/1

[56] References Cited

UNITED STATES PATENTS

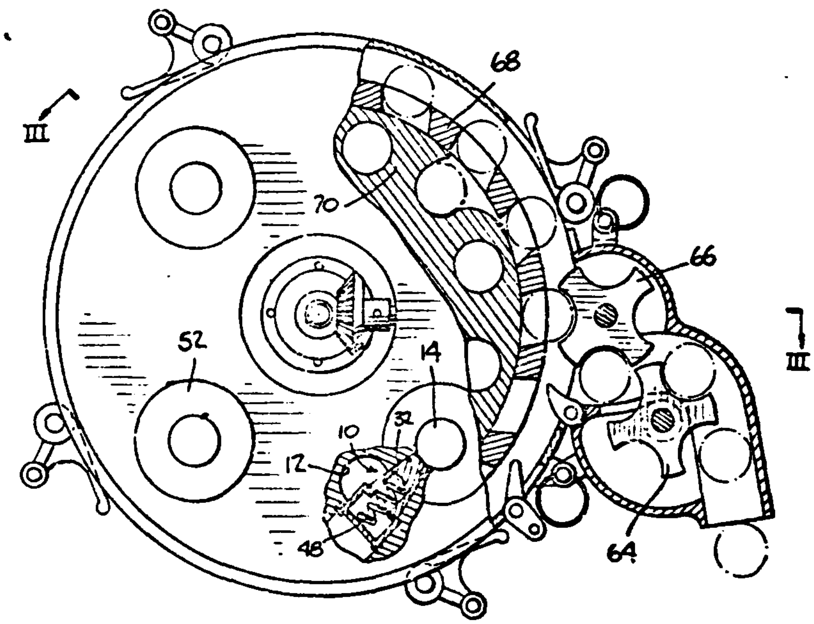
2,947,221	8/1960	Griffin et al.	89/7
1,843,410	2/1932	Von Salis	137/509 X
2,981,153	4/1961	Wilson, Jr. et al.	89/7
3,011,451	12/1961	Griffin	89/7 X
3,202,055	8/1965	Butler	89/7

Primary Examiner—Samuel W. Engle
Attorney—Bailin L. Kuch et al.

[57] ABSTRACT

A valve has a conical passageway which is obturated by a conical spool. The spool is preloaded closed by spring means, and is operated by the hydraulic presence of the liquid flowing through the passageway.

6 Claims, 3 Drawing Figures



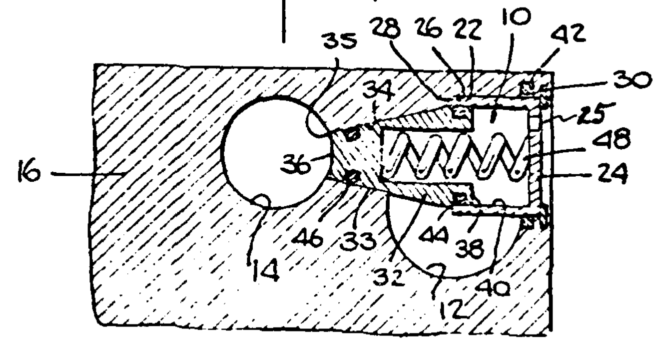

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Fig. 1.

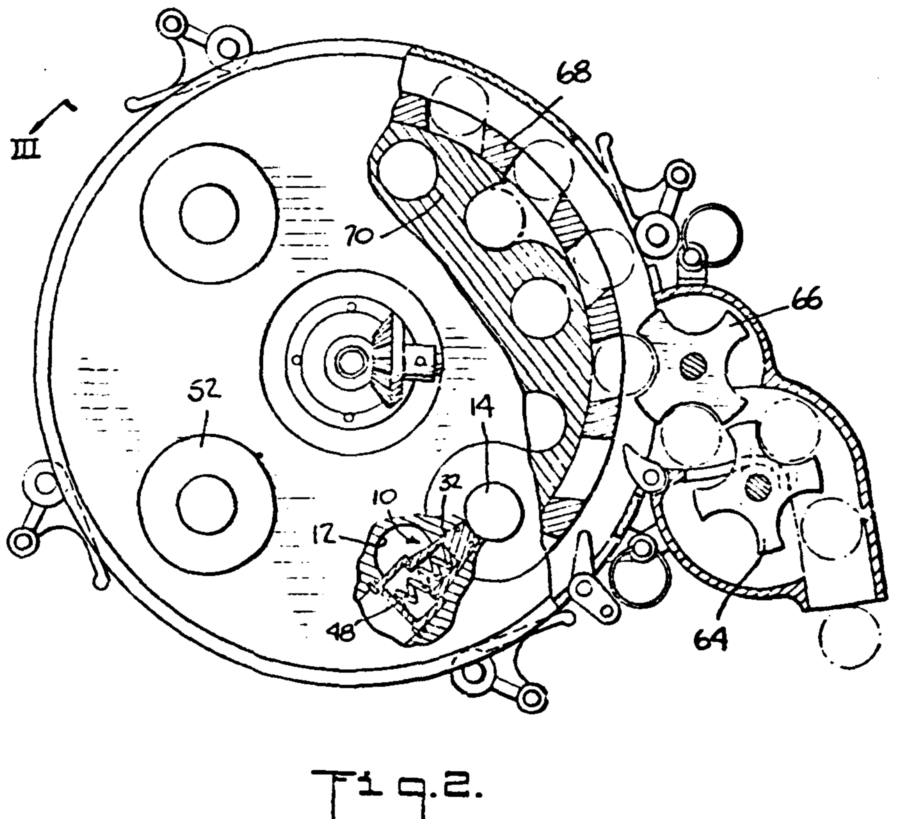
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Fig. 2.

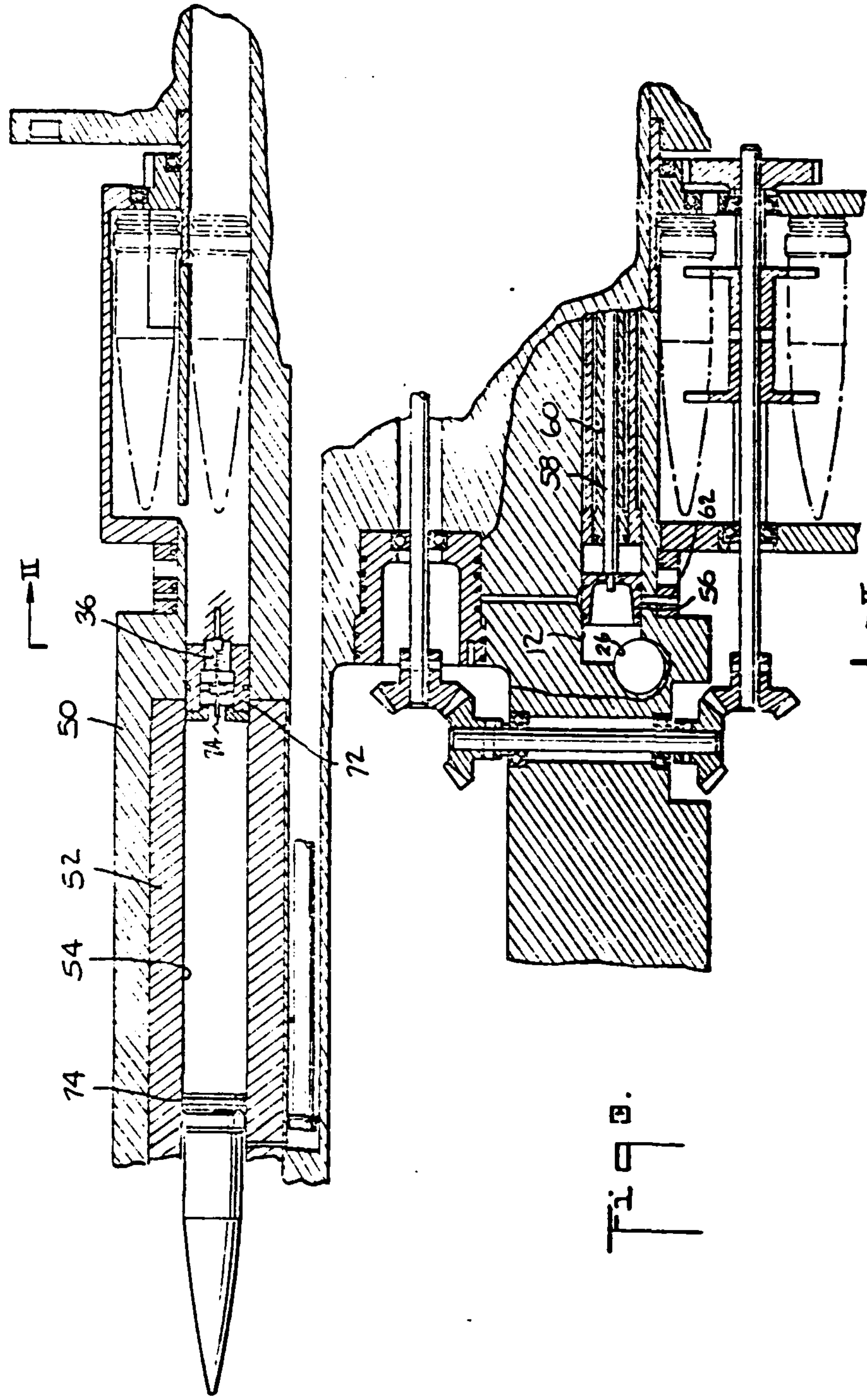

Fig. 3.

ZERO ULLAGE INJECTION VALVE

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates to high rate of flow, rapid actuation valves, and is particularly adapted to high rate of fire, liquid propellant guns.

2. Prior Art

Low rate of fire, liquid propellant or initiant guns are disclosed in U.S. Pat. No. 3,455,202, issued July 15, 1969 to Dixon et al., utilizing a quasi-spool valve; and U.S. Pat. No. 3,537,352, issued Nov. 3, 1970 to R.W. Joyce, utilizing a ball valve. A liquid propellant gun having a high rate of flow spool valve is disclosed in U.S. Patent application Ser. No. 148,833, filed June 1, 1971 by D.P. Tassie

SUMMARY OF THE INVENTION

In the prior art liquid propellant guns, the passageways to the chamber for liquid propellants trap some of these liquids, which then cannot be utilized in the combustion process, and which drain away between shots, producing enclosed volumes containing ambient atmosphere. The next time the chamber is filled with liquid, the trapped atmosphere is forced into the chamber. It is known that decreasing the size of a passageway decreases the ullage that it causes; however, decreasing the diameter of a passageway also decreases the rate of liquid flow therethrough.

The object of this invention is to provide an injection valve which does not introduce any ullage, yet which permits the use of a relatively large diameter passageway.

A feature of this invention is the provision of a valve having a conical passageway which is obturated by a conical spool. The spool is preloaded closed by spring means; and is operated by the hydraulic pressure of the liquid flowing through the passageway.

BRIEF DESCRIPTION OF THE DRAWING

These and other objects, advantages and features of the invention will be apparent from the following specification thereof taken in conjunction with the accompanying drawing in which:

FIG. 1 is a longitudinal cross-sectional view of a conical spool injection valve embodying this invention;

FIG. 2 is a transverse cross-sectional view of a battery type gun embodying the valve of FIG. 1 taken along plane II—II of FIG. 3; and

FIG. 3 is a longitudinal cross-sectional detail view taken along plane III—III of FIG. 2.

DESCRIPTION OF THE INVENTION

As seen in FIG. 1, the conical spool injection valve 10 intercouples a supply volume 12 of liquid with a utilization volume 14, all shown disposed in a block 16. In the embodiment of a gun utilizing liquid propellants shown in FIGS. 2 and 3, the supply volume is an injection cylinder 12, and the utilization volume is a firing chamber 54, both of which have parallel longitudinal axes. The longitudinal axis of the valve is perpendicular to the axes of the chambers, being diametral to the firing chamber, and eccentric to the injection cylinder. The valve includes a cylindrical sleeve 22 closed at its aft end by a transverse wall 24 having an air vent 25 and held in a mating cylindrical bore 26 by a forward bore shoulder 28 and an aft C-clip 30. A spool 32 includes a conical portion 33 which fits in a mating conical bore 34 extending from an opening 35 in the side wall of the chamber 14 to the bore 26, and whose forward end terminates in a truncated face 36 and whose aft end 38 is cylindrical to mate with and slide in the bore 40 of the sleeve 22. Suitable ring seals 42, 44 and 46 are also provided. A helical compression spring 48, captured between and within the sleeve and the spool, biases the spool forwardly from the sleeve to obturate the conical bore 34.

The liquid propellant gun shown in FIGS. 2 and 3 includes a stationary receiver 50 having four gun barrels 52 with respective firing chambers 54. Two propellant liquids are supplied to each firing chamber by two respective injection cylinders 12. Each cylinder 12 includes a hollow spool 56 fixed to a rod 58 which is journalled through a piston 60. An inlet port 62 is coupled to a source of liquid, and the end of the cylinder opens on the respective conical spool injection valve.

Projectiles are fed by a feeder sprocket 64 to a hand off sprocket 66 into a feed ring 68 and then by a scoop ring 20 to a respective chamber 54. A bolt 72 having a firing electrode 74 is reciprocable aft of the chamber. The respective bolts, spools and pistons may all be cam controlled.

A cycle of operation may be considered to start after a projectile has been fired from a gun barrel, as seen in FIG. 3. The bolt 72 unlocks and moves aft, uncovering the opening 36. The hollow spool 56 moves aft, uncovering the inlet port 62. The piston 60 moves aft, sucking liquid into the cylinder through the inlet port 62 and the hollow spool 56, while the spring 48 holds the conical spool 32 of the injection valve closed. The hollow spool 56 moves forward, covering the inlet port 62. A projectile is fed by the scoop into alignment with the firing chamber forward of the bolt 72. The bolt moves forward to the inject position whereat the ring seal 74 of the projectile is forward of the opening 36 and the bolt is aft of the opening. The piston moves forward in the injection stroke, developing relative hydraulic pressure which bears against the conical spool 32 to overcome the bias of the spring 48 to open the injection valve. Liquid propellant flows through the valve into the chamber, pushing the projectile forward. The piston halts in its forward position, the relative hydraulic pressure falls off as the projectile moves forward, the spring 48 closes the injection valve. The bolt is moved forward to its locked position whereat it covers the opening 35, protecting the injection valve from firing gas pressure and seating the projectile rotating band into the rifling of barrel. The propellant is ignited and the projectile is fired.

It will be appreciated that the opening 35 into the inner face of the cylinder 54 is concave and the bolt wall is convex-cylindrical, and not flat as the smaller end face 36 has been described. Ideally, the end face of the spool may be made concave-cylindrical to mate with the opening and the bolt, and means provided to prevent rotation of the spool (e.g., a square post fixed to the sleeve and journalled in a square blind bore in said spool.) Practically, the end face of the spool may be made flat and tangential to the cylinder 54, and the resulting ullage will be insignificant.

While there has been shown and described a preferred embodiment of this invention, it will be appreciated that the invention may be embodied otherwise than as herein specifically illustrated or described, and

that certain changes in the form and arrangement of parts and in the specific manner of practicing the invention may be made without departing from the underlying idea or principles of this invention within the scope of the appended claims.

What is calimed is:

1. A gun comprising:
a gun barrel having a propellant combustion chamber;
a cylinder having an interior bore;
a valve body;
a truncated conical bore in said body having
an opening in its sidewall interfacing said interior bore of saiD cylinder, and
its smaller cross-section opening into the interior sidewall surface of said chamber;
a truncated conical spool disposed for longitudinal reciprocation in said conical bore and having
its smaller cross-section face substantially congruent to said smaller cross-section opening of said conical bore and substantially forming a portion of said interior surface of said chamber;
spring means normally biasing said spool to dispose its said smaller face into said smaller opening of said conical bore to thereby obturate said conical bore, with said smaller face being flush with said interior sidewall surface of said chamber, thereby providing said sidewall surface with a uniform surface, free of lacunae.

2. A gun according to claim 1 further including:
a cylindrical bore in said valve body longitudinally aligned with and extending from and having a diameter larger than the larger cross-section end of said conical bore; and
a cylindrical plug disposed in said cylindrical bore and having a cylindrical blind bore therein for receiving said spool when it is displaced against said bias of said spring means.

3. A gun according to claim 2 further including:
an additional cylindrical blind bore in said spool;
said spring means being a helical compression spring and disposed in part in said blind bore of said plug and in part in said blind bore of said spool.

4. A gun according to claim 1 further including:
a source of fluid propellant coupled to said bore of said cylinder;
a piston disposed in said bore of said cylinder for pumping fluid propellant against said conical spool for displacing said conical spool against said bias of said spring means and thereby passing fluid propellant into said conical bore and thence into said chamber.

5. A gun according to claim 1 further including:
means disposed in said gun barrel for varying the volume of said chamber.

6. A gun according to claim 5 wherein:
said means for varying the volume of said chamber includes
a projectile and
a gun bolt.

* * * * *

United States Patent [19]

Ashley

[11] **3,783,737**

[45] **Jan. 8, 1974**

[54] **SEAL**

[75] Inventor: **Eugene Ashley**, Burlington, Vt.

[73] Assignee: **General Electric Company**, Burlington, Vt.

[22] Filed: **Feb. 4, 1972**

[21] Appl. No.: **223,643**

[52] **U.S. Cl.** .... **89/7, 89/26, 277/212 C**

[51] **Int. Cl.** **F41f**

[58] **Field of Search** .... 89/7, 26; 102/DIG. 1; 285/110; 92/240, 245, 246; 277/212 C, 236

[56] **References Cited**

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539,733	5/1895	Gerdom	89/26
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FOREIGN PATENTS OR APPLICATIONS

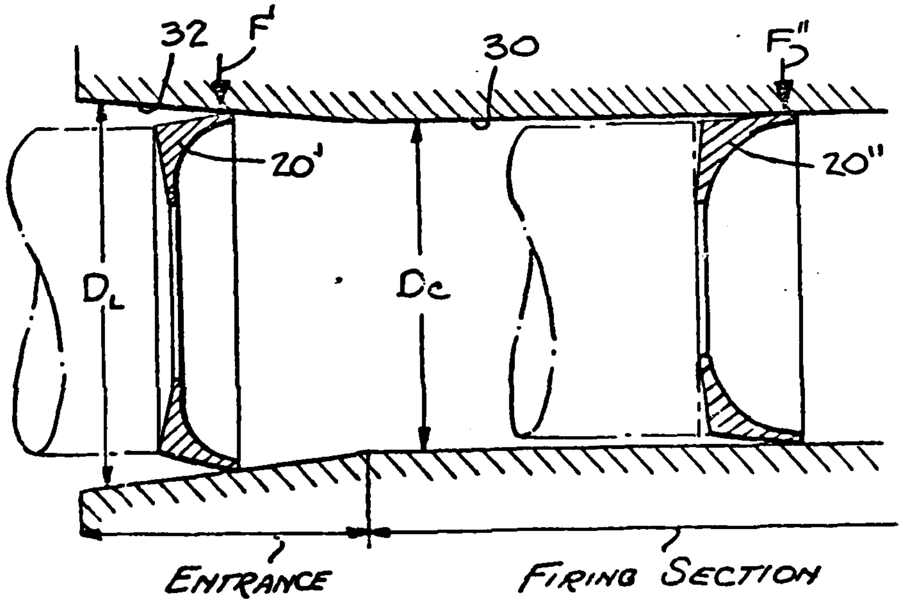
1,096,697	1/1961	Germany	277/212 C

Primary Examiner—Stephen C. Bentley
Attorney—Bailin L. Kuch et al.

[57] **ABSTRACT**

A liquid propellant gun is provided with a seal and a multi diametered chamber which centripetally deflects the seal to generate a preseating force thereon.

3 Claims, 4 Drawing Figures



PRIOR ART

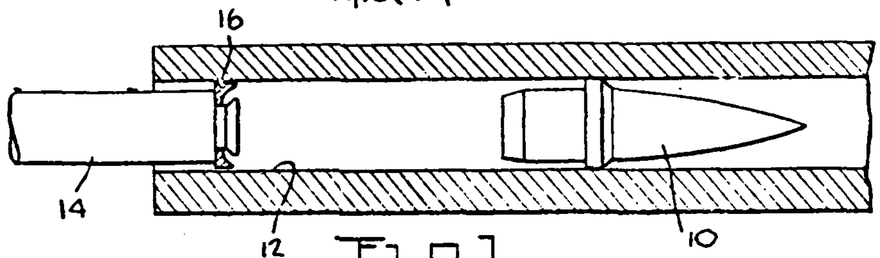


Fig.1.

Fig.2.

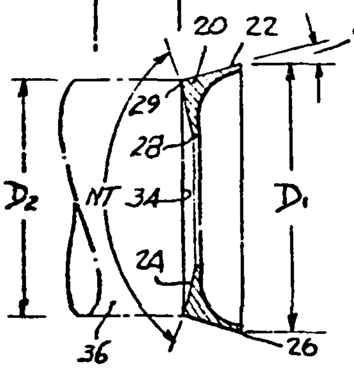


Fig.3.

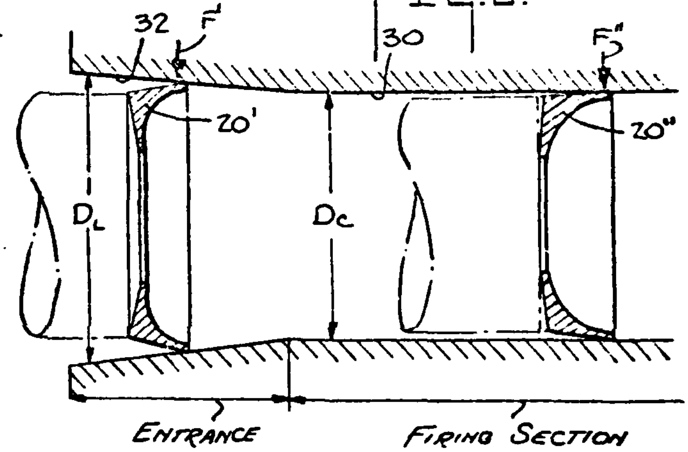
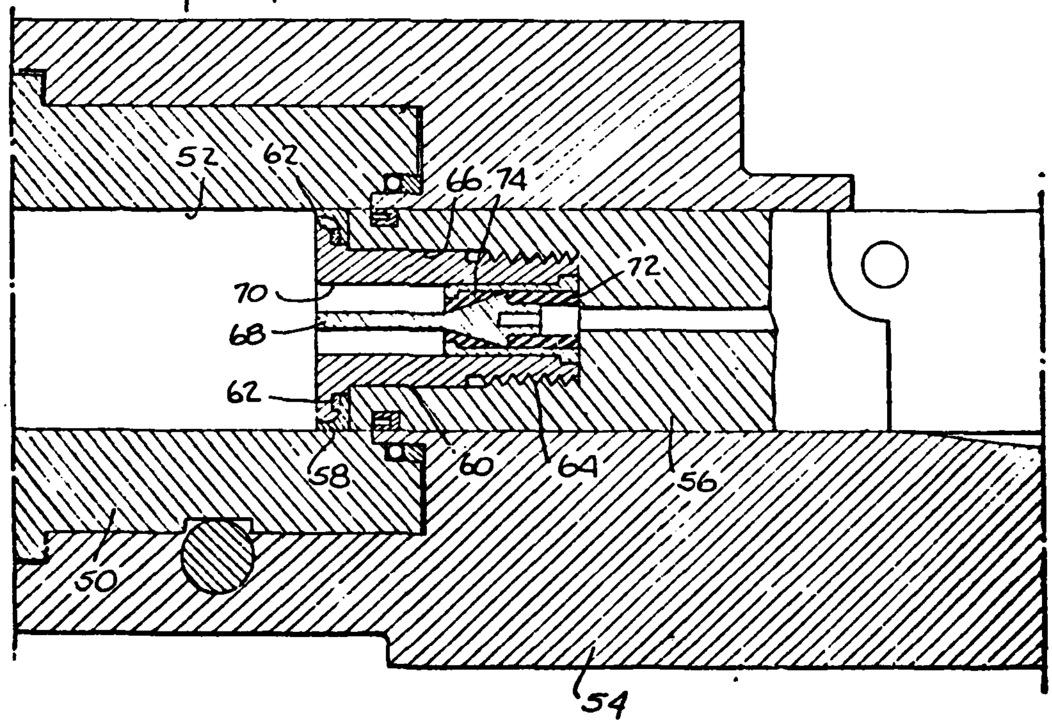


Fig.4.



SEAL

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates to a centripetally preloaded, annular seal for combustion apparatus, especially adapted to use in a liquid propellant gun. The invention herein described was made in the course of or under a contract or subcontract thereunder with the Department of the Navy.

2. Prior Art

Annular breech seals are shown in U.S. Pat. Nos. 3,114,290; 3,354,780; and 3,403,596, suitable for conventional guns firing caseless ammunition. A liquid propellant gun which is well adapted to utilize the seal of the present invention is shown in U.S. Pat. application Ser. No. 148,833, filed June 1, 1971 by D.P. Tassie, to which reference may be had for details of the total system not herein shown.

SUMMARY OF THE INVENTION

Liquid propellant guns, like other guns firing caseless ammunition, must be provided with seals to prevent the escape of gas from the firing chamber during the combustion process.

Accordingly, it is an object of this invention to provide a seal for a cylindrical combustion chamber which is preseated before firing.

A feature of this invention is the provision of a seal and a multi diametered chamber which centripetally deflects the seal to generate a preseating force thereon.

BRIEF DESCRIPTION OF THE DRAWING

FIG. 1 is a schematic in longitudinal cross section of a prior art firing chamber, such as is shown in Ser. No. 148,833 supra;

FIG. 2 is a schematic in longitudinal cross section of a seal embodying this invention;

FIG. 3 is a schematic in longitudinal cross-section of a multi diametered firing chamber and seal embodying this invention; and

FIG. 4 is a detail view in longitudinal cross-section of a gun embodying this invention.

DESCRIPTION OF THE PREFERRED EMBODIMENT

In guns firing conventional cased ammunition, the interface between the combustion chamber and the gun bolt is sealed by the cartridge case.

In the prior art guns, as shown in FIG. 1, utilizing liquid propellant and a projectile **10** without a cartridge case, the interface between the combustion chamber **12** and the gun bolt **14** is closed by a seal **16** which is carried by the bolt and has a slight clearance with respect to the wall of the chamber. This allows the seal to be easily inserted into the chamber during the loading operation. After firing, as the combustion gases are developed in the chamber and the gas pressure rises, a small flow of gas develops past the periphery of the seal. This flow induces a pressure differential between the stagnant gas within the chamber and the flowing gas without the chamber. The higher pressure within the chamber causes the seal to expand centrifugally until it abuts the chamber wall and obstructs further gas flow. From this condition on, the seal is self-energizing in that a higher gas pressure within the chamber tends to seat the seal yet more firmly. The disadvantage of such conventional seals is that the small initial leakage causes heating and erosion of the seal, and often allows foreign particles to enter the gap and to interfere with the seating of the seal.

The combination of the seal and the firing chamber shown in FIGS. 2 and 3 provides a full seating of the seal with both the chamber and the gun bolt before firing.

The seal **20** is shown in its free state in FIG. 2, and is transversely annular, with a substantially triangular longitudinal cross-section. The seal's outer annular surface **22** has a small positive taper forward the front, shown as angle PT, its aft transverse surface **24** may be slightly conical internally, shown as angle NT, and its hypotenuse may be concave. If the seal is subjected to an annular, centripetal force on its forward edge annulus **26**, a compound deflection will occur which pivots the longitudinal cross section about a transverse annular axis, so that the major diameter D_1 of the forward edge-annulus is reduced, reducing the angle PT, and the aft transverse surface **24** becomes less conical, increasing the angle NT.

The chamber **30** has an internal diameter D_c with a tapered aft entrance or lead-in portion **32** having an initial aft internal diameter D_L greater than D_1 and a forward internal diameter equal to D_c. FIG. 3 shows the seal **20'** in its free state. As the seal advances through the lead-in portion towards the firing portion the forward edge annulus **26** engages the wall **32** and is progressively deflected by the peripheral force F', to reduce its major diameter D_1. When the forward edge annulus **26** enters the firing section as at **20''**, the peripheral force F'' plateaus at a maximum, while the major diameter D_1 plateaus at a minimum which is the diameter of the firing chamber D_c, with the forward edge annulus firmly seated against the chamber wall. As a result of the compound deflection, the aft inner edge annulus **28** of the seal will be firmly seated against the face **34** of the bolt **36**. Thus the preseating of the forward edge **26** against the chamber wall and the preseating of the inner edge **28** against the bolt face will preclude the flow of gas or particles past the seal, and any resultant erosion.

After firing, as the gas pressure builds up, the aft outer edge annulus **29** of the seal will expand, until the outer annular surface **22** contacts the chamber wall along its full length, with the seal minor diameter D_2 also equal to Dc, and the aft face **24** contacting the bolt face **34** along its full length. Thereafter, under increased gas pressure, the seal and the chamber will expand together. After discharge, the seal's elasticity will cause it to return to the condition of **20''**.

In a gun embodiment, a barrel **50** having a chamber **52** similar to 30/32 is locked into a receiver **54**. A bolt **56** reciprocates in the chamber and carries a chamber seal **58**, similar to **20**, which is held by a retainer **60** and a resilient washer **62**. The aft end of the retainer is threaded at **64** into a bore **66** in the bolt. An electrode **68** is fixed in a bore **70** through the retainer and bolt by an insulator **72** and a wedge **74**. As the bolt advances into the chamber entrance **32** the seal **58** is distorted by the chamber wall and preseated thereagainst as described with respect to FIG. 3.

What is claimed is:

1. A combustion apparatus comprising:

a vessel having a substantially cylindrical chamber therein,

said chamber having an internal wall having an aft entrance portion merging into a forward firing portion,

said aft entrance portion having an aft, initial, internal diameter and a forward, final diameter, said initial diameter being greater than said final diameter;

a piston for obturating said forward portion of said chamber,

said piston having a resilient, integral, annular seal mounted thereon,

said seal being transversely annular, with substantially triangular longitudinal cross-section, having an outer annular, approximately cylindrical face and an aft, annular, approximately transverse face,

said outer face having a forward-most annular edge, which in the free state of said seal is greater in external diameter than the remainder of said outer face, and which in the free state is less than said initial internal diameter of said chamber and greater than said final internal diameter of said chamber;

whereby, as said piston is advanced longitudinally forwardly through said entrance portion of said chamber, said forward-most annular edge of said seal and only said forward-most annular edge engages said wall of said chamber, and the external diameter of said forward-most annular edge is progressively reduced thereby, providing a continuous edge sealing between said seal and said wall; and

said piston has a forward facing transverse surface aft of and adjacent to said seal;

said aft, annular, approximately transverse face of said seal having an inner annular edge which in the free state of said seal is longitudinally forward of the remainder of said aft face,

whereby, as said external diameter of said forward-most annular edge of said seal is progressively reduced, said inner annular edge is displaced progressively longitudinally aft, and said inner annular edge, and only said inner annular edge engages said forward facing transverse surface, providing a continuous edge sealing between said seal and said surface.

2. A combustion apparatus according to claim 1 wherein:

said chamber aft entrance portion has a negative taper from its aft initial diameter to said final diameter, said final diameter, being the diameter of said forward firing portion.

3. A combustion apparatus according to claim 1 wherein:

said apparatus is a gun;

said vessel is a gun barrel; and

said piston is a gun bolt.

* * * * *

United States Patent [19]

Ashley

[11] **4,011,817**

[45] **Mar. 15, 1977**

[54] **LIQUID PROPELLANT WEAPON SYSTEM**

[75] Inventor: **Eugene Ashley**, Burlington, Vt.

[73] Assignee: **General Electric Company**, Burlington, Vt.

[22] Filed: **May 7, 1975**

[21] Appl. No.: **575,283**

[52] **U.S. Cl.** **102/38;** 102/40

[51] **Int. Cl.**[2] **F42B 5/16;** F42B 9/14

[58] **Field of Search** .... 102/38, 40, 43 R, 24 R; 89/7

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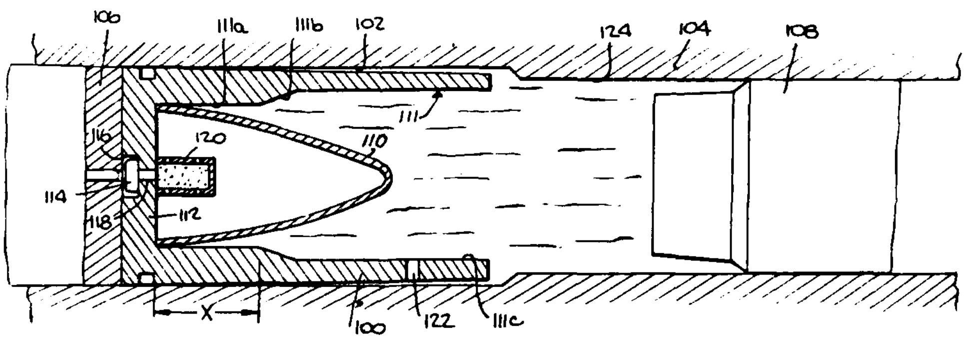
Primary Examiner—David H. Brown
Attorney, Agent, or Firm—Bailin L. Kuch

[57] **ABSTRACT**

A gun and ammunition system is provided which utilizes the difference in density between the combustion gases and the charge of liquid propellant as the source of energy for the injec ion of propellant into the combustion chamber.

19 Claims, 18 Drawing Figures



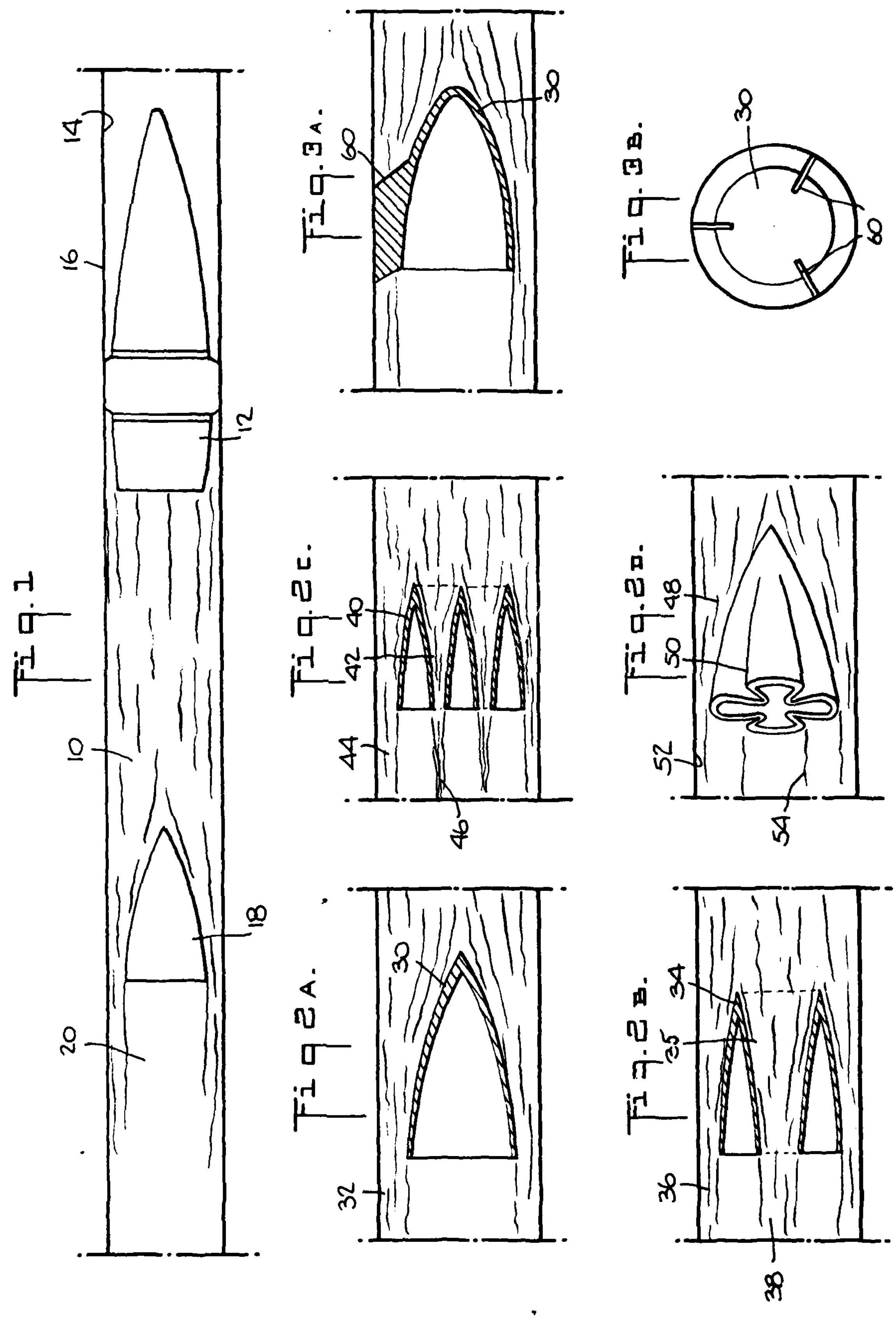


Fig. 1
Fig. 3A.
Fig. 3B.
Fig. 2C.
Fig. 2D.
Fig. 2A.
Fig. 2B.
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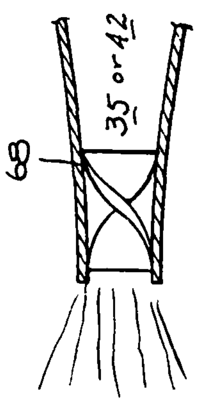


Fig. 4C.

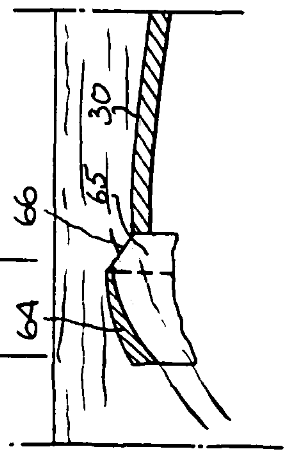


Fig. 4B.

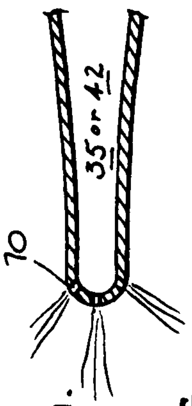


Fig. 4D.

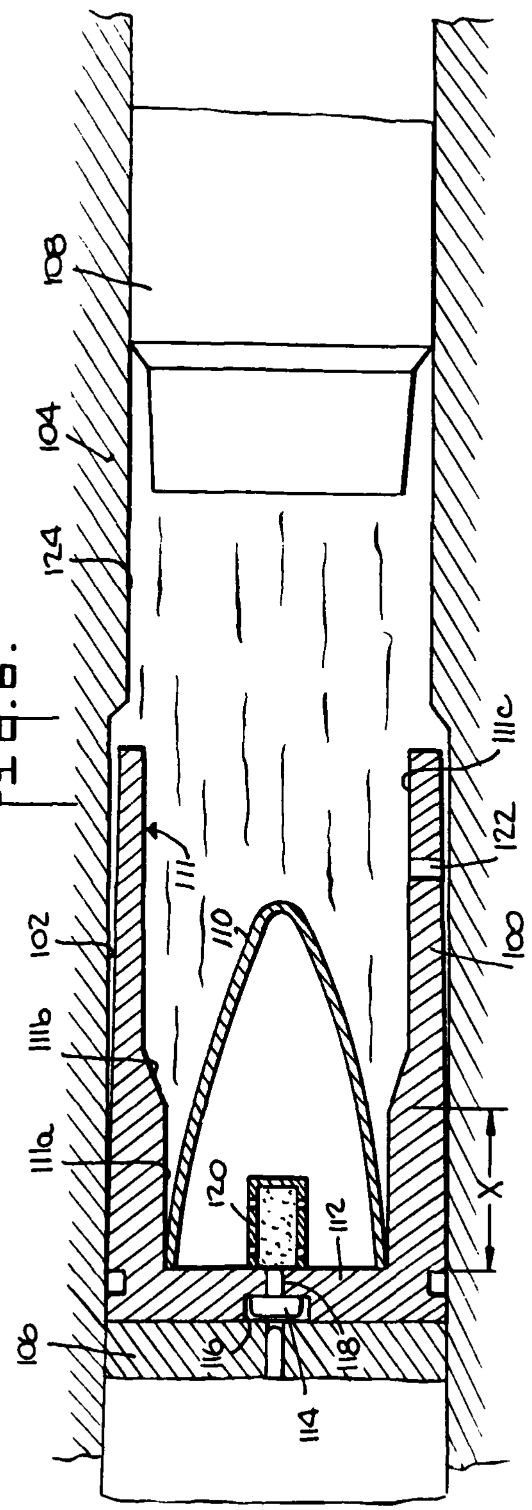


Fig. 6.

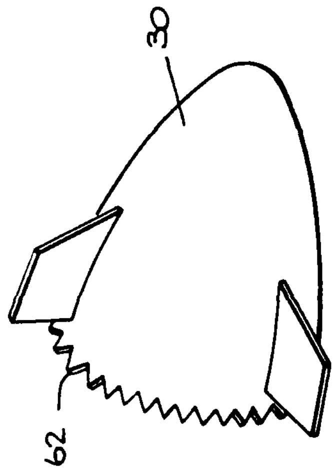


Fig. 4A.

FIG. 5A.

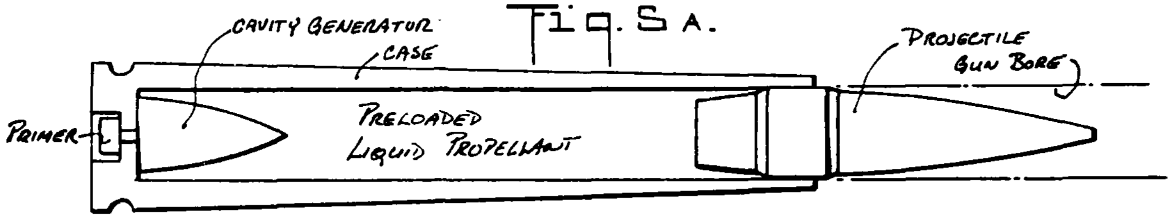


FIG. 5B.

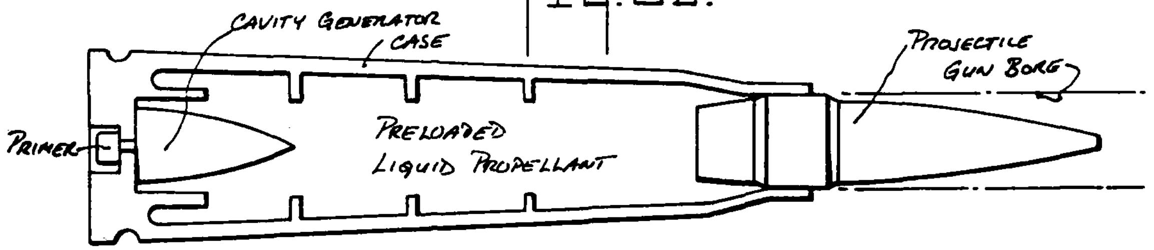


FIG. 5C.

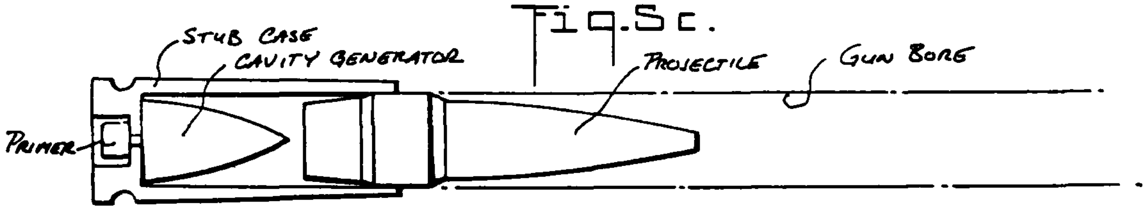


FIG. 5D.

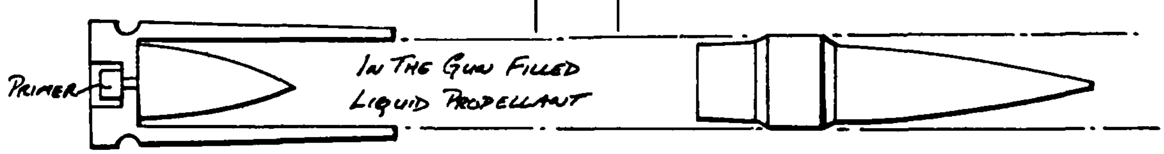


FIG. 5E.

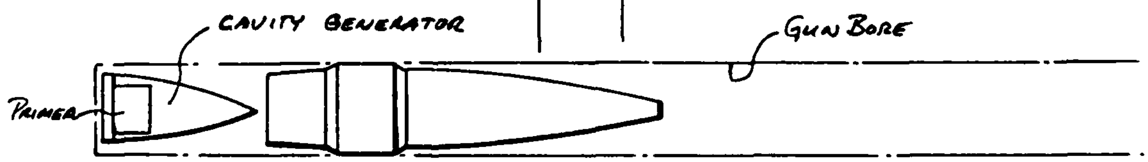
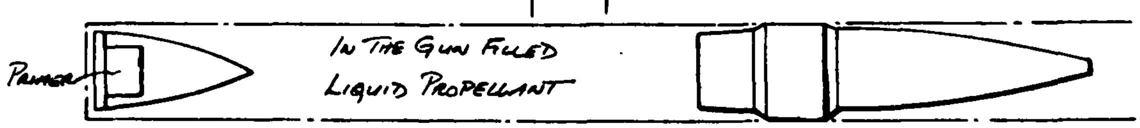


FIG. 5F.



LIQUID PROPELLANT WEAPON SYSTEM

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates to weapons systems employing a liquid propellant, and particularly to such systems wherein the propellant is continuously pumped into the combustion chamber aft of the projectile as the projectile advances along the firing bore.

2. Prior Art

In my earlier patent application, Ser. No. 469,507, now abandoned, filed May 13, 1974, I disclosed a gun and ammunition system utilizing a round of ammunition carrying a relatively narrow diameter and relatively high mass projectile in a relatively wide and relatively low mass sabot which is initially accelerated by a primary propellant charge in the combustion chamber aft of the projectile and which is passed during a relatively extended period of time to the combustion chamber. Additional prior art is cited and discussed in that application which is hereby incorporated by reference.

SUMMARY OF THE INVENTION

An object of this invention is to provide a gun and ammunition system utilizing a liquid propellant traveling charge which is simpler than the area differential system disclosed in Ser. No. 469,507 supra.

A feature of this invention is the provision of a gun and ammunition system which utilizes the difference in density between the combustion gases and the charge of liquid propellant as the source of energy for the injection of propellant into the combustion chamber.

During the combustion of the propellant, an extremely steep inertial gradient exists between the face of the gun bolt and the projectile; and the lighter combustion gas propagates forwardly into the liquid charge of propellant. An injector device is provided which has a lower average density than the density of the liquid charge and which utilizes this difference in density to control the entrance of liquid propellant in the combustion zone or chamber. The injector device also defines and controls the interface between the liquid propellant and the combustion gas and provides a true traveling charge effect.

BRIEF DESCRIPTION OF THE DRAWING

These and other objects, features, and advantages of this invention will be apparent from the following specification thereof taken in conjunction with the accompanying drawing in which:

FIG. **1** is a schematic view of a gun and ammunition system embodying this invention;

FIGS. **2A**, **2B**, **2C**, and **2D** are schematic views of various species of cavity generators embodying this invention;

FIGS. **3A** and **3B** are schematic views of a fin-stabilized cavity generator embodying this invention;

FIGS. **4A**, **4B**, **4C**, and **4D** are schematic detail views of additional species of cavity generators embodying this invention;

FIGS. **5A** and **5B** are schematic longitudinal cross-section views of two species of a cased, pre-loaded liquid propellant round of ammunition embodying this invention;

FIGS. **5C** and **5D** are schematic longitudinal cross-section views of a stub-cased, in-the-gun-filled round of ammunition before and after loading with liquid propellant, respectively, and embodying this invention;

FIGS. **5E** and **5F** are schematic longitudinal cross-section views of a caseless, in-the-gun-filled round of ammunition before and after loading with liquid propellant, respectively, and embodying this invention; and

FIG. **6** is a detail view in longitudinal cross-section of the round of FIG. **5D**.

DESCRIPTION OF THE EMBODIMENTS

Taylor cavity formation and subsequent Helmholtz mixing are considered fundamental mechanisms in bulk-loaded liquid propellant guns. Behavior of the liquid gas interface, and hence of combustion processes, are attributed to these phenomena. The dyanmics of two-phase flow under accelerations as extreme as those in guns support this supposition, and evidence exists to confirm it. Though chamber pressures are higher than critical, and transition between phases takes place differently than at lower pressure levels, large density differences must exist between burned and unburned charges. The less dense regions of combustion products undoubtedly migrate through the denser unburned propellant. Much turbulence and liquid break-up certainly occurs.

FIG. **1** shows a liquid propellant traveling charge **10** behind a projectile **12** in a bore **14** in a gun barrel **16**. Acceleration is taking place toward the right. Behind the liquid charge is shown a new component: a cavity generator **18.** This is here shown as an ogive having a circular arc body of revolution. Behind the cavity generator **18** is the combustion zone **20** containing the hot gases which constitute the products of combustion. The cavity generator substantially separates the main body of the liquid charge from the combustion gases.

The design of the cavity generator **18** gives it another more significant function. It is constructed so that its density is less than that of the liquid charge **10** surrounding it. In the high inertial gradient associated with acceleration in the gun barrel, the lighter cavity generator will tend to penetrate the liquid charge. This is analogous to the penetration of gas in the Taylor cavity theory as applied to guns. As the cavity generator penetrates, it will displace liquid which necessarily flows rearward of the generator in a relative sense. The cavity generator thus acts as an injector system, controlling the rate at which liquid charge enters the combustion zone. As it penetrates into the liquid charge, the cavity generator literally shapes and controls a quasi-Taylor cavity.

FIG. **1** shows the cavity generator as a solid displacement body of appropriate density to aid in visualization. However, a solid body of revolution is not necessarily the most practical arrangement for actual application. It occupies volume in the chamber before firing, and it must be expelled as debris after the projectile leaves the muzzle. It is advantageous to reduce its bulk.

One way of reducing the bulk of the cavity generator is to make the generator hollow. Instead of a solid body, it becomes a thin shell, open at the rear and filled with combustion gas. The products of combustion will have variable density as pressure changes, but the average density of the products of combustion and the generator will always be less than that of the unburned liquid charge.

In this approach, the lightest, thinnest design is utilized. The cavity generator acts more as a gas-filled

A_c = bore area

Penetration velocity gives a measure of the flow rate of propellant into the combustion zone. This can be combined with equations for the energy balance within the gun chamber to calculate chamber pressure and projectile motion as functions of time.

What is claimed is:

1. A round of ammunition comprising:
   a projectile having a first average density;
   a cavity generator having a second average density; and
   a charge of liquid propellant having a third average density which is greater than said second average density;
   said charge of liquid propellant being disposed between said projectile and said cavity generator;
   said generator being adapted to enter into said charge and form a cavity in the aft portion of said charge which is aft of said generator.

2. A round of ammunition comprising:
   a projectile having a first average density;
   a cavity generator having a second average density;
   a charge of a combustible liquid having a third average density which is greater than said second average density;
   said charge of combustible liquid being disposed between said projectile and said cavity generator; and
   means for providing a volume of combustion gas aft of said cavity generator for forwardly advancing said cavity generator into said charge of combustible liquid; and
   means for passing displaced combustible liquid aftwardly past said cavity generator into said volume of combustion gas.

3. A round of ammunition according to claim 2 wherein:
   said first average density is greater than said third average density.

4. A round of ammunition according to claim 2 further including:
   container means for holding said projectile forwardmost, and said charge of liquid propellant and said cavity generator in serial order aft thereof.

5. A round of ammunition according to claim 4 wherein:
   said means for providing combustion gas comprises a charge of explosive disposed in the aft portion of said container means.

6. A round of ammunition according to claim 4 wherein:
   said means for passing displaced liquid comprises an annular opening defined by and between said cavity generator and said container means.

7. A round of ammunition according to claim 6 wherein:
   said cavity generator has a trailing edge with a plurality of serrations therein which are bent outwardly and serves as flow spoilers.

8. A round of ammunition according to claim 6 wherein:
   said cavity generator has a trailing edge with a plurality of tabs spaced by aperatures and webs which are bent inwardly to serve as flow deflectors.

9. A round of ammunition according to claim 6 wherein:
   said container means has a cylindrical inner wall having a first inner diameter;
   said projectile has a maximum second outer diameter substantially equal to said first diameter; and
   said cavity generator has a maximum third outer diameter less than said first diameter.

10. A round of ammunition according to claim 9 wherein:
   said cavity generator has a plurality of radially extending fins, thereby having an overall maximum diameter equal to said first diameter.

11. A round of ammunition according to claim 6 wherein:
   said cavity generator has an ogive of a circular arc body of revolution, whose point is directed forwardly and whose base is directed aftwardly.

12. A round of ammunition according to claim 11 wherein:
   said cavity generator has a plurality of longitudinally extending flutes in its outer surface.

13. A round of ammunition according to claim 11 wherein:
   said cavity generator is a hollow envelope, closed forwardly and open aftwardly.

14. A round of ammunition according to claim 11 wherein:
   said cavity generator comprises a plurality of ogives fixed together in spaced apart relation, the spaces between said ogives serving as fluid passing nozzles.

15. A round of ammunition according to claim 14 wherein:
   each of said nozzles has a swirl generator.

16. A round of ammunition according to claim 14 wherein:
   each of said nozzles has a plurality of orifices.

17. A round of ammunition according to claim 11 wherein:
   said cavity generator has a central fluid passing nozzle formed along its longitudinal axis.

18. A round of ammunition according to claim 17 wherein:
   said nozzle has a swirl generator.

19. A round of ammunition according to claim 17 wherein:
   said nozzle has a plurality of orifices.

* * * * *

United States Patent [19] [11] 4,023,463

Tassie [45] May 17, 1977

[54] LIQUID PROPELLANT GUN (CHECK VALVE AND DAMPER)

[75] Inventor: Douglas Pray Tassie, Williston, Vt.

[73] Assignee: General Electric Company, Burlington, Vt.

[22] Filed: June 10, 1976

[21] Appl. No.: 694,867

[52] U.S. Cl. 89/7; 417/349; 417/381

[51] Int. Cl.² F41F 1/04

[58] Field of Search .... 89/7, 9, 1 K; 417/349, 417/377, 381; 60/39.01

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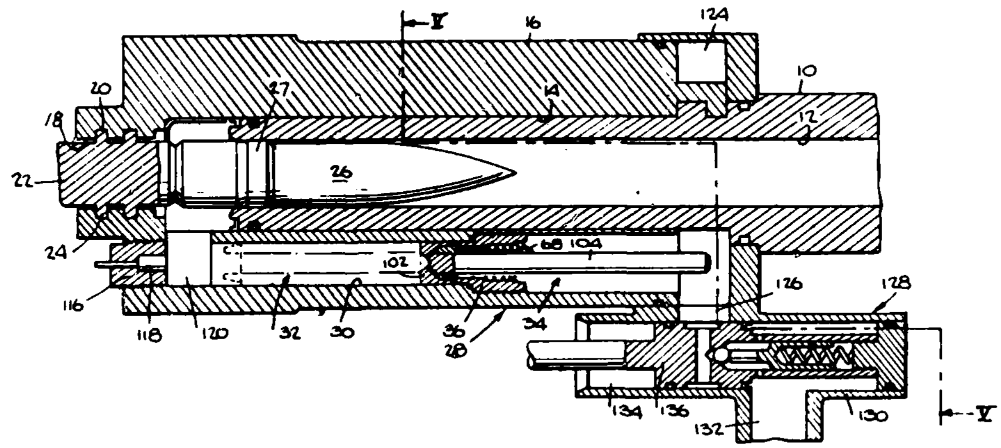
3,763,739	10/1973	Tassie	89/7

Primary Examiner—David H. Brown
Attorney, Agent, or Firm—Bailin L. Kuch

[57] ABSTRACT

A liquid propellant gun utilizes a differential piston having a plurality of bores through its head, which head divides the liquid propellant pumping chamber from the combustion chamber, and propellant supply means providing liquid propellant under pressure into said pumping chamber, which propellant under pressure both advances the piston to enlarge the pumping chamber and to decrease the combustion chamber and injects and atomizes a predetermined quantity of propellant through said bores from said pumping chamber into said combustion chamber, and a check valve which precludes flow of liquid propellant under pressure from said piston to said propellant supply means and damps said piston at the end of its combustion stroke by means of a damping cylinder.

11 Claims, 5 Drawing Figures



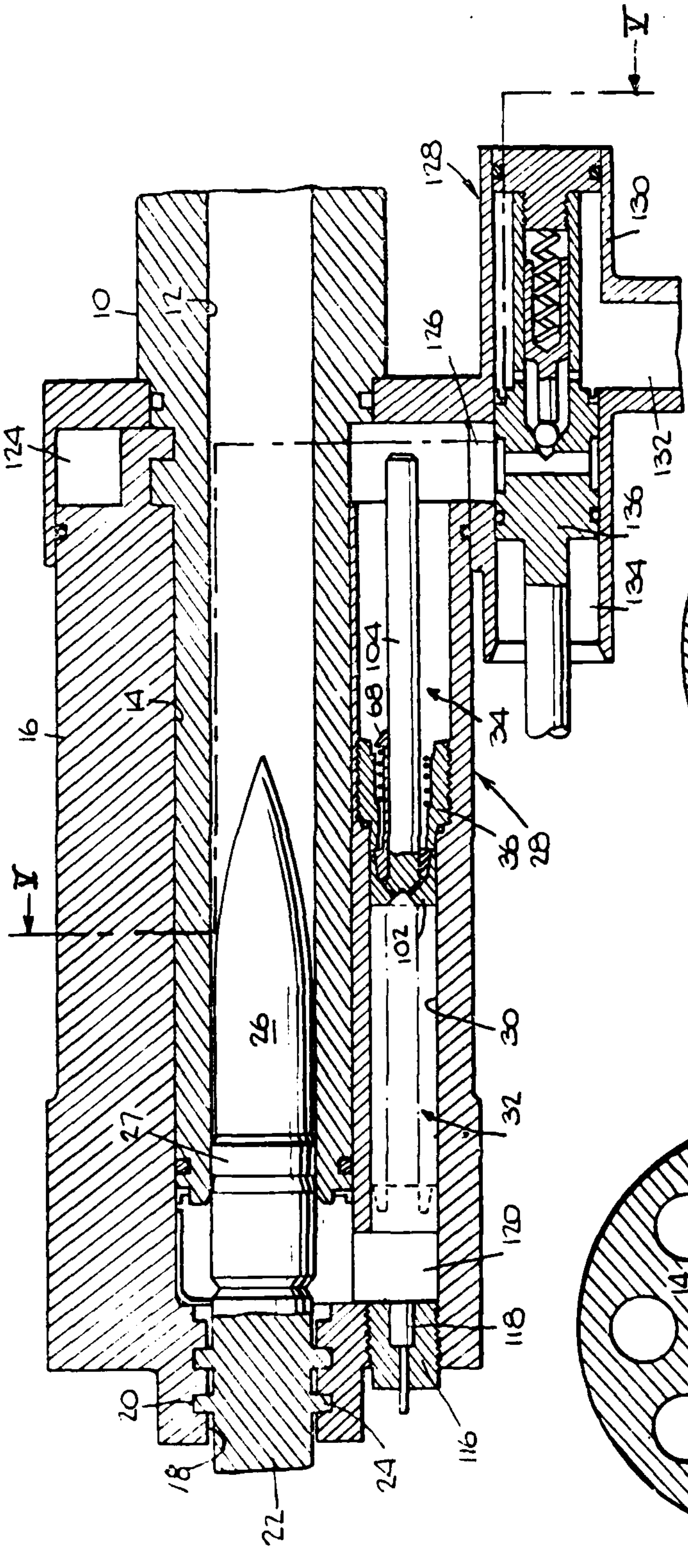


Fig.1.

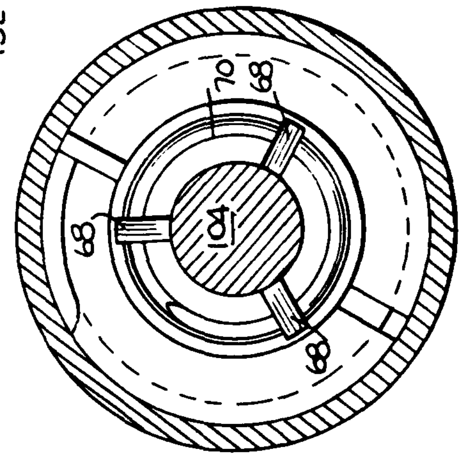


Fig.3.

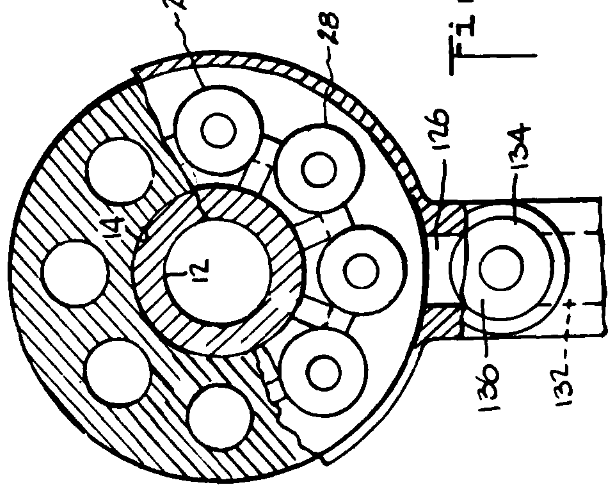


Fig.5.

Fig. 2.

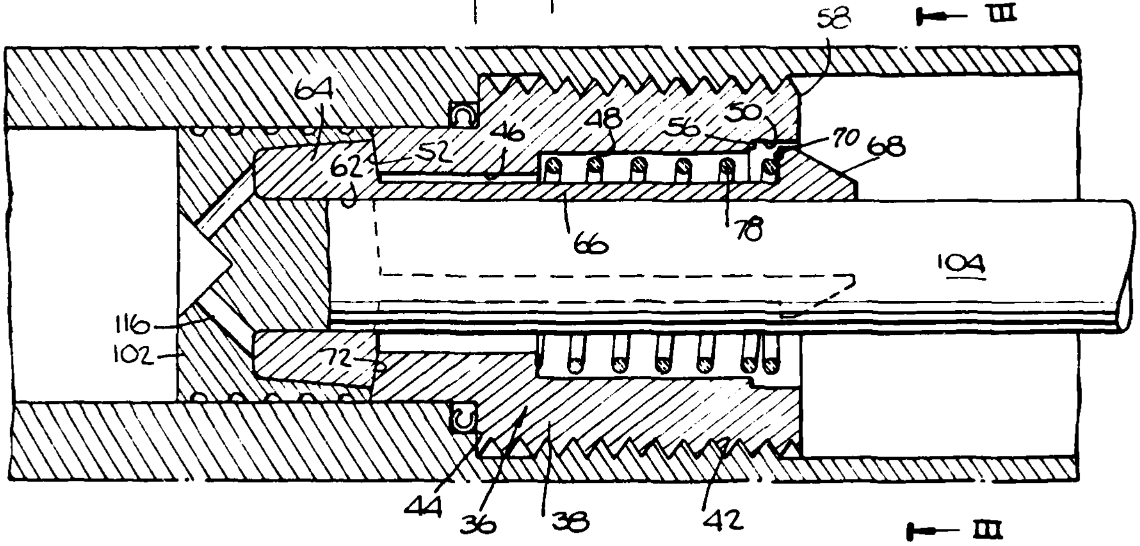

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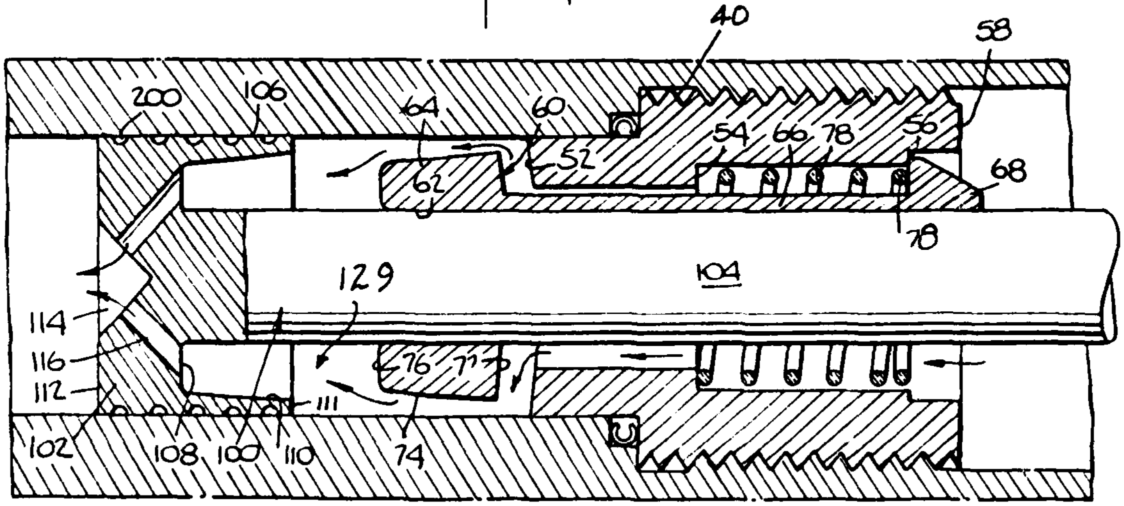
Fig. 4.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UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

PATENT NO. : 4,023,463

DATED May 17, 1977

INVENTOR(S) Douglas Pray Tassie

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below

Column 1, line 10 change "afte" to --after--; line 34 change "different" to --differential--; line 46, after "combustion" insert --chamber--, change "abd" to --and--; line 56, change "different" to --differential--.
Column 2, line 68 change "III" to --111--.
Column 3, line 11 delete "or manifold"; line 12, after "way" insert --or manifold--; line 31, change "surface" to --surfaces--; line 40 change "has" to --had--.
Claim 4, delete lines 29, 30, 31, and 32.
Claim 7, line 24, change "said" to --and--.
Claim 10, line 46, change "alve" to --valve--.

Signed and Sealed this

thirtieth **Day of** *August 1977*

[SEAL]

Attest:

RUTH C. MASON
Attesting Officer

C. MARSHALL DANN
Commissioner of Patents and Trademarks

LIQUID PROPELLANT GUN (CHECK VALVE AND DAMPER)

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates to liquid propellant guns utilizing a differential piston to provide continued or regenerative injection of propellant into the combustion chambers afte initial ignition of propellant in the chamber.

2. Prior Art

Liquid propellant guns utilizing differential pistons to pump propellant into the combustion chamber during combustion are now well known. Early work is described in a Final Report of Nov. 19, 1953—Jan. 31, 1956 under contract DA-36-034-ORD-1504RD, Project TS1-47-8 by V. M. Barnes, Jr. et al which apparently in part corresponds to Jukes et al, U.S. Pat. No. 3,138,990 filed Oct. 9, 1961; in a report No. 17-2 of June 15, 1954 under contract NOrd-10448 by C. R. Foster et al; and in a Final Report of Sept. 1, 1957 under contract NOrd 16217, Task 1, by L. C. Elmore et al. Other patents of interest are J. W. Treat, Jr., U.S. Pat. No. 2,922,341, filed Nov. 7, 1955; E. J. Wilson, Jr. et al U.S. Pat. No. 2,981,153, filed Nov. 14, 1952; C. M. Hudson, U.S. Pat. No. 2,986,072, filed Nov. 19, 1952; and E. J. Vass, et al, U.S. Pat. No. 3,690,255 filed Oct. 1, 1970. Certain of these patents, e. g. Jukes et al, show the use of valves to control the entrance of propellant into the combustion chamber.

An object of this invention is to provide an improved check valve for a liquid propellant gun having a combustor assembly utilizing a different piston which will preclude ullage at the supply face of said piston and which will provide damping of said piston at the end of its combustion stroke.

A feature of this invention is the provision of a liquid propellant gun utilizing a differential piston having a plurality of bores through its head, which head divides the liquid propellant pumping chamber from the combustion chamber, and propellant supply means providing liquid propellant under pressure into said pumping chamber, which propellant under pressure both advances the piston to enlarge the pumping chamber and to decrease the combustion and injects abd atomizes a predetermined quantity of propellant through said bores from said pumping chamber into said combustion chamber, and a check valve which precludes flow of liquid propellant under pressure from said piston to said propellant supply means and damps said piston at the end of its combustion stroke.

RELATED CASES

Subject matter directed to the different piston disclosed herein is claimed in the application of A. R. Graham, filed concurrently herewith, Ser. No. 694,866. Subject matter directed to scaling using a plurality of combustor assemblies disclosed herein is claimed in the application of A. R. Graham, filed concurrently herewith Ser. No. 694,869.

BRIEF DESCRIPTION OF THE DRAWING

These and other objects, advantages and features of the invention will be apparent from the following specification thereof taken in conjunction with the accompanying drawing in which:

FIG. 1 is a detail view in longitudinal cross-longitudinal cross-section of a gun incorporating a combustor assembly embodying this invention;

FIG. 2 is an enlarged detail of FIG. 1 of the combustor assembly in the end of propellant injection mode;

FIG. 3 is a transverse view in cross-section taken along the plane III—III of FIG. 2;

FIG. 4 is an enlarged detail of FIG. 1 of the combustor assembly in the propellant filling mode; and

FIG. 5 is a transverse view in cross-section of a gun incorporating a plurality of the combustor assemblies of FIG. 1 taken along the folded plan V—V.

DESCRIPTION OF THE PREFERRED EMBODIMENT

This invention, as shown in FIG. 1, may be incorporated in a liquid propellant gun of the type shown by D. P. Tassie in U. S. Pat. No. 3,763,739. However, the invention as here shown utilizes a monopropellant, although the regenerative piston system is applicable to bipropellants as well.

The gun system includes a gun barrel **10**, having a gun bore **12**, which is fixed in a forward bore **14** of a housing **16**. The housing has an aft bore **18**, with a plurality of locking recesses **20**, which receives a gun bolt **22** having a plurality of locking lugs **24**. A projectile **26** having a rotating band **27** may be inserted through the aft bore **18** and pushed forwardly into the gun bore **12** by the bolt **22**, which bolt is then locked in and to the housing. The bank **27** makes a gas tight seal with the bore.

The housing **16** may have one, or as shown in FIG. **5**, a plurality of combustor assemblies **28**. As shown in FIGS. **1**, **2** and **4**, each combustor assembly includes a longitudinal bore **30** having a combustion chamber portion **32** and a liquid propellant inlet chamber portion **34**. A coaxial check valve **36** is fixed in the bore **30** and includes an outer annular housing **38** which is externally threaded at **40** to engage threads **42** and a shoulder **44** in the bore **30**, and has a longitudinal bore in three stepped portions: a portion **46** having the smallest diameter, a portion **48** having an intermediate diameter, and a portion **50** having the largest diameter. The housing **38** has a left face **52**, an internal shoulder **54**, an internal shoulder **56**, and a right face **58**. A sleeve **60** has an longitudinal bore **62**, a left, truncated conical, annular head portion **64**, and a tail portion including an intermediate portion provided by a plurality (here shown as three) of longitudinally extending, circumferentially spaced apart, beams **66**, and a right portion provided a like plurality of heel, enlarged terminations **68** on each beam. The right portion has a left face **70** which will abut the shoulder **56**, the left portion has a right face **72** which will mate with and will seal against the face **52**, a conical, peripheral face **74**, and a left face **76**. A helical compression spring **78** is disposed between the shoulder **54** and the face **70** and biases the sleeve **60** to the right.

A piston **100** has a head portion **102** which slides in the combustion chamber portion **32** and a stem portion **104** which slides in the bore **62** of the sleeve **60**. The head portion has an L-ring longitudinal cross-section with an outer-peripheral surface **106** for sliding engagement with the wall of the chamber **32**, a right transverse annular surface **108** which will mate with and will seal against the face **76**, a right conical annular surface **110** which will mate with and will seal against the face **74**, a transverse annular surface III which will mate with

and will seal against the face 52 a left face 112 having a conical recess 114, and a plurality of bores 116 disposed in an annular row and interconnecting the face 108 with the recess 114.

The left end of the combustion chamber 30 is closed by a plug 116 which carries a spark plug 118. A respective radial bore 120 communicates between the respective combustion chamber 32 and the left end of the bore 12.

The right end of each liquid propellant inlet chamber portion 34 opens into an annular or manifold passageway 124, which in turn is open, at 126, to a propellant supply valve 128. The valve includes a housing 130 having an inlet port 132, a cylinder 134, and a spool 136. The spool may be cam controlled, as shown in U.S. Pat. No. 3,763,739 for synchronization with the other gun functions.

As shown in FIG. 1, before loading, the valve 128 is closed and the piston 100 is in its righthandmost position wherein it is nested with and sealed to the check valve 36. A projectile 26 is inserted into the gun bore 12 and the bolt 22 is closed and locked. The spool 136 is shifted to the left, opening the valve 128, admitting liquid propellant under pressure into the manifold 124. Propellant under pressure passes into the chamber portion 34 and into the longitudinal recesses between the beams 68, and applies pressure against the surface 72 of the portion 64 to shift the portion, against the bias of the spring 78, away from the surface 52, to permit the flow of liquid propellant around the portion 64 and against the surface 108 and 110 of the head 102 of the piston. This pressure provided by the incoming liquid propellant pushes the piston head to the left, creating and enlarging the available volume of a propellant pumping chamber portion 129 and decreasing the available volume of the combustion chamber portion. A small quantity of the liquid propellant passes through the bores 116 into the combustion chamber portion during this shifting of piston head, and thus a quantity of air which has entered when the bolt was open, plus this quantity of liquid propellant, are compressed and trapped in the combustion chamber. The liquid propellant is atomized as it passes through the bores, and the total quantity and the size of the droplets is a function, inter alia, of the diameter of the bores, the velocity of the piston and the pressure of the liquid propellant. When the piston head has reached its maximum excursion in compression, that is, leftmost travel, the liquid pressure in the pumping chamber portion 129 equals the liquid pressure in the supply manifold 124 and the supply chamber portion 34 and the spring 78 drives the sleeve 60 to the right, thereby closing the check valve 36. This quantity of compressed air and atomized propellant in the combustion chamber portion adjacent the sparkplug is predetermined and repeatable, and serves as a primer for the combustion of the main charge of propellant disposed in the supply chamber portion. Ignition of this primer is provided by the sparkplug. Ignition of the primer generates combustion gas whose pressure drives the piston to the right to increase the volume of the combustion chamber portion and to decrease the volume of the pumping chamber portion. The difference in areas of the two faces of the piston generates a difference in pressure in the two chambers so that liquid propellant is continually forced through the bores 116 into the combustion chamber at a controlled rate. The piston head is displaced continually to the right towards the closed check valve 36. As the piston head closes onto the annulus 74 of the check valve the remainder of the liquid propellant trapped therebetween provides an energy absorbing function and absorbs the energy of the moving piston head as it impacts against the check valve annulus, without any ullage. The interface surfaces 110 and 74 should be conical, approaching a cylinder, to provide maximum travel time for trapped fluid to absorb energy and pass through the bores, yet not so cylindrical as to trap liquid and prevent such liquid from reaching and passing through the bores.

The interface between the piston stem 104 and the bore 62 may be without seals, since any leakage from the pumping chamber portion will merely pass back into the supply chamber portion. The L-ring section 106 provides an effective seal between the hot gun gas in the combustion chamber and the relatively cold liquid in the pumping chamber portion, in that there is a different in pressure on the piston head which provides for the flow of liquid propellant from the pumping chamber to the combustion chamber, which precludes any flow of gun gas from the combustion chamber to the pumping chamber.

To provide lubrication between the piston head 102 and the wall of bore 32, a plurality of shallow, helical grooves 200 may be provided in the peripheral surface of the piston head, communicating from the left face 112 to the right face, adjacent 110. Liquid propellant will be forced through these apertures at the same time as through the bores 116, and will lubricate this interface. All lubricant passing into the combustion chamber portion will be in a swirl pattern, ensuring good mixing, and will be burned, either as primer, or as part of the main charge. A fresh supply of lubricant is provided during each firing cycle, and will clean out any particles which may lodge in the grooves.

Lubrication of the interface between the piston stem and the check valve sleeve is also provided by the liquid propellant.

The leakage propellant will act as a booster as well as a primer. The piston compresses air in front of it, and then creates a two-phase mixture in front of it, which on ignition, acts as a booster charge. A small booster charge results in a much faster initial chamber pressure rise which improves ballistic efficiency.

What is claimed is:

1. A pump comprising:

a cylinder having a longitudinal bore with a longitudinal axis, an inner wall, an inlet end and an outlet end;

a check valve coaxial with said longitudinal axis and closing said cylinder bore inlet end, including:

an outer annular housing fixed to and sealed within said cylinder bore inner wall, and having a longitudinal bore coaxial with said longitudinal axis and a first, substantially transverse, cylinder bore inlet end remote face,

an annular sleeve disposed within said housing bore and having an annular head portion remote from said cylinder bore inlet end, a tail portion provided by a plurality of circumferentially spaced apart beams extending longitudinally from said head portion and proximal to said cylinder bore inlet end; and having a longitudinal bore coaxial with said longitudinal axis,

said sleeve head portion having a first, substantially transverse, cylinder bore inlet end remote face,

and a second, substantially transverse, cylinder bore inlet end proximal face, and

spring means biasing said sleeve towards said cylinder bore inlet end so that said sleeve head second face abuts and seals against said housing first face;

a piston having a head portion journaled within and sealing against said cylinder bore wall and a stem portion journaled within said sleeve bore,

said piston head portion having a first, substantially transverse, check valve distal face and a second, substantially transverse, check valve proximal face,

said piston head second face adapted to abut and seal against said sleeve first face.

2. A pump according to claim 1 wherein:
said housing and the distal ends of said sleeve beams have interengaging means to limit the travel of said sleeve relative to said housing against the bias of said spring.

3. A pump according to claim 1 wherein:
said piston head second face and said sleeve head portion have mating faces which will congruently interfit without voids.

4. A pump according to claim 3 wherein:
said piston head second face is substantially conical to provide a longitudinal cross-section of a L-ring seal.
said housing and the distal ends of said sleeve beams have interengaging means to limit the travel of said relative to said housing against the bias of said spring.

5. A pump according to claim 1 further including:
supply means coupled to said inlet end of said cylinder bore for providing a supply of liquid under pressure thereto, the liquid adapted to flow to said check valve, between said sleeve beam portions and against said sleeve head portion second face to displace said sleeve against the bias of said spring to create a passageway around said sleeve head portion to said piston head second face to displace said piston head from said sleeve head portion to create and fill a void between said piston head and said sleeve head.

6. A pump according to claim 5 wherein:
said piston head has a plurality of bores communicating between said first and said second piston head faces,

means coupled to said cylinder bore outlet end for returning said piston head to said sleeve head portion whereon liquid trapped in said void progressively absorbs the kinetic energy of said piston head through ejection of such liquid through said plurality of bores.

7. A liquid propellant gun comprising:
a gun bore having a projectile receiving chamber;
a gun bolt for opening and closing a projectile receiving chamber behind a projectile; and
a pump comprising:
a cylinder having a longitudinal bore with a longitudinal axis, an inner wall, an inlet end and an outlet end, said outlet end communicating with said projectile receiving chamber;
a check valve coaxial with said longitudinal axis and closing said cylinder bore inlet end, including:

an outer annular housing fixed to and sealed within said cylinder bore inner wall, and having a longitudinal bore coaxial with said longitudinal axis and a first, substantially transverse, cylinder bore inlet end remote face,

an annular sleeve disposed within said housing bore and having an annular head portion remote from said cylinder bore inlet end, a tail portion provided by a plurality of circumferentially spaced apart beams extending longitudinally from said head portion and proximal to said cylinder bore inlet end; and having a longitudinal bore coaxial with said longitudinal axis,

said sleeve head portion having a first, substantially transverse, cylinder bore inlet end remote face, and a second, substantially transverse, cylinder bore inlet end proximal face, and

spring means biasing said sleeve towards said cylinder bore inlet end so that said sleeve head second face abuts and seals against said housing first face;

a piston having a head portion journaled within said sealing against said cylinder bore wall and a stem portion journaled within said sleeve bore,

said piston head portion having a first, substantially transverse, check valve distal face and a second, substantially transverse, check valve proximal face,

said piston head second face adapted to abut and seal against said sleeve first face.

8. A gun according to claim 7 wherein:
said piston head second face and said sleeve head portion have mating faces which will congruently interfit without voids.

9. A gun according to claim 7 wherein:
said housing and the distal ends of said sleeve beams have interengaging means to limit the travel of said sleeve relative to said housing against the bias of said spring.

10. A gun according to claim 7 further including:
supply means coupled to said inlet end of said cylinder bore for providing a supply of liquid under pressure thereto, the liquid adapted to flow to said check alve, between said sleeve beam portions and against said sleeve head portion second face to displace said sleeve against the bias of said spring to create a passageway around said sleeve head portion to said piston head second face to displace said piston head from said sleeve head portion to create and fill a void between said piston head and said sleeve head.

11. A gun according to claim 10 wherein:
said piston head has a plurality of bores communicating between said first and said second piston head faces,

means coupled to said cylinder bore outlet end for returning said piston head to said sleeve head portion whereon liquid trapped in said void progressively absorbs the kinetic energy of said piston head through ejection of such liquid through said plurality of bores.

* * * * *

United States Patent [19]

Ashley

[11] 4,011,817

[45] Mar. 15, 1977

[54] LIQUID PROPELLANT WEAPON SYSTEM

[75] Inventor: Eugene Ashley, Burlington, Vt.

[73] Assignee: General Electric Company, Burlington, Vt.

[22] Filed: May 7, 1975

[21] Appl. No.: 575,283

[52] U.S. Cl. 102/38; 102/40

[51] Int. Cl.[2] F42B 5/16; F42B 9/14

[58] Field of Search .... 102/38, 40, 43 R, 24 R; 89/7

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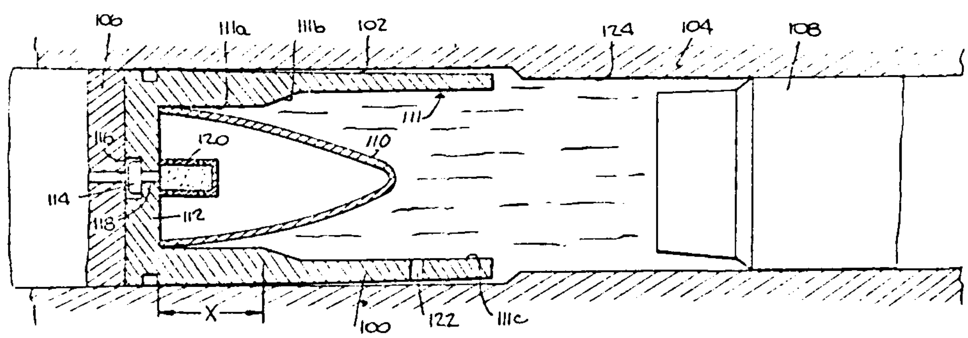
Primary Examiner—David H. Brown
Attorney, Agent, or Firm—Bailin L. Kuch

[57] ABSTRACT

A gun and ammunition system is provided which utilizes the difference in density between the combustion gases and the charge of liquid propellant as the source of energy for the injection of propellant into the combustion chamber.

19 Claims, 18 Drawing Figures



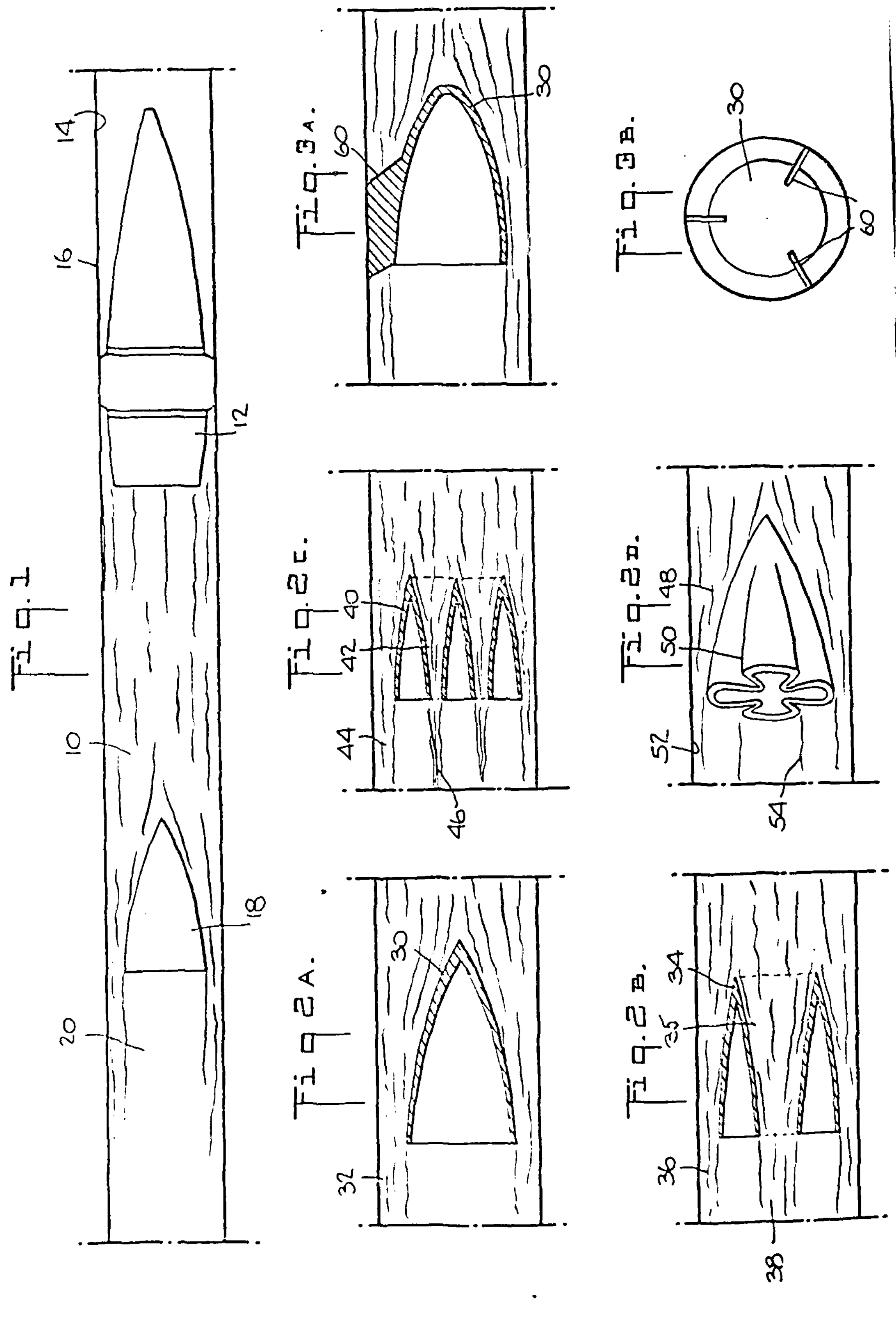


Fig. 1
14
16
12
10
18
20
Fig. 3A
60
30
Fig. 3B
30
60
Fig. 2C
40
42
44
46
Fig. 2D
48
50
52
54
Fig. 2A
30
32
Fig. 2B
34
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36
38

FIG. 4.

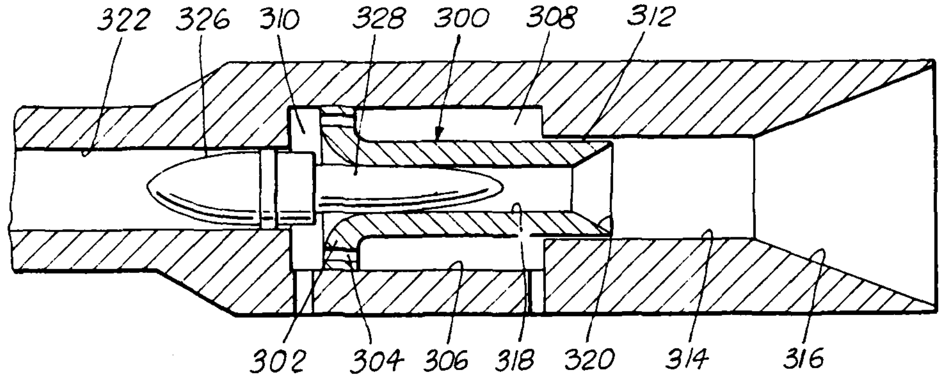


FIG. 5.

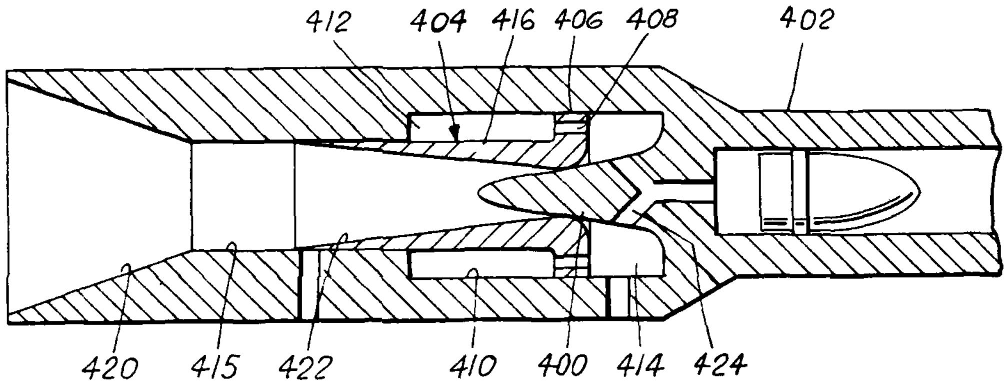
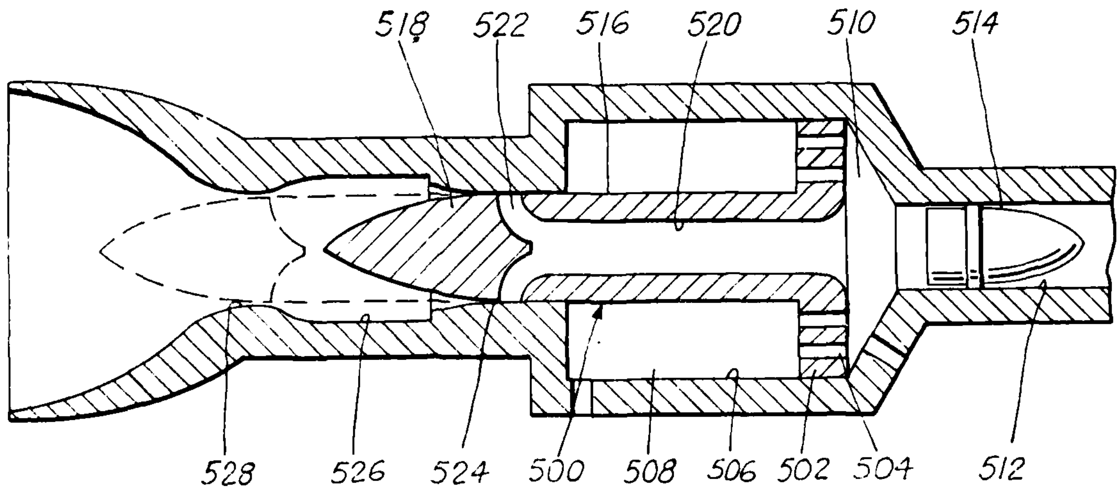


FIG. 6.



UNITED STATES PATENT OFFICE

CERTIFICATE OF CORRECTION

Patent No. 4,043,248 Dated August 23, 1977

Inventor(s) Melvin J. Bulman and Alfred Rapp Graham

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

[75] Inventors: Melvin John Bulman, Shelburne, Vermont
Alfred Rapp Graham, Burnt Hills, New York

Column 2,
line 64 change "enlarged" to --elongated--.
Column 3, line 3 change "cross-section" to --cross-sectional--; line 25 after "through" insert --the--; line 29 delete "chamber"; line 51 after "magnitude" insert --or--.
Column 5, line 14 change "to" to --a--; line 38 change "piston of" to --piston to--.

Signed and Sealed this

Fourteenth **Day of** *March 1978*

[SEAL]

Attest:

RUTH C. MASON
Attesting Officer

LUTRELLE F. PARKER
Acting Commissioner of Patents and Trademarks

LIQUID PROPELLANT GUN (RECOILLESS REGENERATIVE PISTON)

BACKGROUND OF THE INVENTION

1. *Field of the Invention*

This invention relates to liquid propellant guns utilizing a differential piston to provide continued or regenerative injection of the propellant into the combustion chamber after initial ignition, and more particularly to such guns having a balancing nozzle for recoilless operation.

2. Prior Art

Liquid propellant guns utilizing differential pistons to pump propellant into the combustion chamber during combustion are now well known. Early work is described in a Final Report of Nov. 19, 1953–Jan. 31, 1956 under contract DA-36-034-ORD-1504RD, Project TS1-47-8 by V. M. Barnes, Jr. et al which apparently in part corresponds to Jukes et al, U.S. Pat. No. 3,138,990 filed Oct. 9, 1961; in a report No. 17-2 of June 15, 1954 under contract NOrd-10448 by C. R. Foster et al; and in a Finai Report of Sept. 1, 1957 under contract NOrd 16217, Task 1, by L. C. Elmore et al. Other patents of interest are J. W. Treat, Jr., U.S. Pat. No. 2,922,341, filed Nov. 7, 1955; E. J. Wilson, Jr., et al, U.S. Pat. No. 2,981,153, filed Nov. 14, 1952; C. M. Hudson, U.S. Pat. No. 2,986,072, filed Nov. 19, 1952; and E. J. Vass, et al, U.S. Pat. No. 3,690,255, filed Oct. 1, 1970.

Guns utilizing balancing nozzles to approximate recoilless operation are also now well known. Examples are: C. W. Musser, U.S. Pat. No. 2,924,149, filed Oct. 7, 1957; L. A. Skinner, U.S. Pat. No. 2,965,000, filed Dec. 20, 1960; R. G. Strickland et al, U.S. Pat. No. 3,129,636, filed Sep. 28, 1960; and A. J. Grandy, U.S. Pat. No. 3,338,133, filed Oct. 6, 1965. Musser and Grandy show the use of a frangible disk to close the balancing nozzle until pressure has built up in the combustion chamber. Strickland et al shows a plug attached to the projectile to restrict the balancing nozzle prior to translation of the projectile down the gun barrel. That is, to restrict the flow of exhaust combustion gas through the nozzle during the early phases of the combustion process in the recoilless gun. This restriction causes more rapid pressure buildup and higher acceleration for the projectile. However, the plug is attached to the projectile and this restriction it provides only occurs when the projectile is near the beginning of the gun barrel. Since the projectile has a very high initial acceleration, the plug is in the vicinity of the nozzle for only a very short initial period.

An object of this invention is to provide a recoilless gun wherein the rate of exhaust flow of the combustion gas through the balancing nozzle can be controlled over a major fraction of the combustion period, thereby to permit a more absolute balance of the forces of recoil and counterrecoil to provide a truly recoilless gun.

Another object of this invention is to provide a recoilless gun where the rate of exhaust flow of the combustion gas through the balancing nozzle can be controlled to reduce the blast field generated by the exhaust flow to a desired level. By blast field is meant the shock wave or waves generated in the volume or region of atmosphere surrounding the rear of the gun which is generated by the rapid introduction therein of the large volume of exhaust gas. Controlling the rate of introduction of this gas directly controls the strength of this shock wave and its overpressure.

A feature of this invention is the provision of a liquid propellant gun having a combustion gas responsive displacement mechanism to progressively inject propellant into a combustion chamber from a supply chamber, a gun barrel for the discharge of a projectile, a balancing nozzle for the discharge of combustion gas, and a plug coupled to said mechanism and serving to control the effective cross-section area of said nozzle in response to the displacement of said mechanism.

BRIEF DESCRIPTION OF THE DRAWING

These and other objects, advantages and features of the invention will be apparent from the following specification thereof taken in conjunction with the accompanying drawing in which:

FIG. 1 is a schematic diagram of a gun having a coaxial gun barrel, a differential piston and a balancing nozzle embodying the present invention;

FIG. 2 is a schematic diagram of a gun having a gun barrel with an ammunition feeding mechanism parallel to a differential piston and a balancing nozzle embodying the present invention;

FIG. 3 is a schematic diagram of a gun similar to that of FIG. 2 having a plurality of sets of differential pistons and balancing nozzles disposed in a circular row coaxial to a gun barrel with an ammunition feeding mechanism;

FIG. 4 is a schematic diagram of an additional species of the invention having the differential piston as part of the balancing nozzle;

FIG. 5 is a schematic diagram of a variation of the species of FIG. 4; and

FIG. 6 is a schematic diagram of a variation of the species of FIG. 1.

DESCRIPTION OF THE INVENTION

The invention, as shown in figures, may be incorporated in a liquid propellant gun having a differential area piston for progressively injecting propellant from a supply chamber into a combustion chamber, as shown in Ser. No. 694,865, filed June 10, 1976 by A. R. Graham, and obtaining satisfactory damping through the devices shown in Ser. No. 694,867, filed June 10, 1976 by D. P. Tassie and Ser. No. 694,868, filed June 10, 1976 by A. R. Graham. The controlled leakage mechanism described in Ser. No. 694,866, above, may also be used to advantage herein.

As shown in FIG. **1**, the invention is embodied in a gun having a gun barrel **10** with a rifled bore **12** and a chamber **14** receiving a projectile **16** having a rotating band **18**. The gun barrel extends aftwardly to form a cylinder **20** having a bore **22**, to which is fixed, as by a theaded joint **24**, a balacing nozzle **26** having a throat **28** and a transverse wall **30** with a plurality of longitudinal bores **32** disposed about a central longitudinal bore **34**. A differential piston **36** has a head **38** journaled for reciprocation in the bore **22** and a stem **40** journaled for reciprocation in the bore **34**. The head has a plurality of longitudinal bores **42** extending from the forward face **44** of relatively large cross-sectional area to the aft face **46** of relatively small cross-sectional area. The stem has a longitudinal blind bore **48** extending aftwardly from the forward face **44** and intersected at its aft end by a plurality of radial bores **50**. The aft end of the stem is fixed, as by a threaded joint **52**, to an enlarged cylindrical plug **54** which is journaled for reciprocation in the throat **28**. The plug may be of any desired longitudinal configuration, from a maximum diameter at transverse plane **56** to a minimum diameter at transverse plane **58**

so that as a function of the longitudinal aftward displacement of the plug from the position shown in FIG. 1, a minimum open annular cross-section area (shown as zero in FIG. 1) is provided at the knee 60 to a maximum open annular cross-sectional area. A port 62, in the cylinder 20, for the entry of liquid propellant, a forward port 64 and an aft port 66 for respective sources of ignition are also provided.

The piston head 38, the wall 30 and the bore 22 define a supply chamber 70 for liquid propellant; the piston head 38, the bore 22 and the projectile 16 define a forward combustion chamber 72; the wall 30, the throat 28 and the plug 54 define an aft combustion chamber 74. At the beginning of a cycle the piston head is aft and adjacent to the wall 30. A projectile is inserted into the projectile chamber 14. Liquid propellant is introduced under pressure through the port 62, as by a check valve, not shown, to progressively displace the piston head forwardly, increasing the volume of the supply chamber and decreasing the volumes respectively of the forward and aft combustion chambers. In this process a small quantity of propellant leaks through the bores 42 and 32 into the forward and aft combustion chambers and serves as a primer which is subsequently ignited by ignition sources operable through ports 64 and 66 after the piston head has reached its forwardmost position, as shown in FIG. 1, whereat the plug has minimized the annular opening of the throat of the balancing nozzle.

Upon ignition the combustion chamber gas in the forward combustion chamber acting on the relatively large cross-sectional area of the face 44 of the piston head 38 commences to displace the piston aft, which injects more propellant through the bores 42 and 32. At this time the aft and forward combustion chambers are a substantially closed system, and combustion gas pressure builds up without venting. As the piston moves aft with the plug 54, the throat of the balancing nozzle is progressively opened, permiting the flow of combustion gas out the nozzle from the forward combustion chamber, through the piston bore 48 and bores 50 together with that combustion gas which is generated itself in the aft combustion chamber.

It may be noted the bores 32 and 66 and the combustion in the aft chamber 74 may all be omitted, and all of the balancing gas flow may be provided from the forward chamber 72.

It may also be noted that the regenerative piston, due to the resistance of flow of the liquid propellant through the bores 42 and 32 providing a hydraulic damping function, has a much lower acceleration and a velocity which is an order of magnitude more slower than the projectile. Thus the control exercised over the balancing nozzle by the plug 54 on the regenerative piston can be essentially extended over nearly the full time the projectile is in the gun barrel.

The longitudinal axis of the regenerative piston may be displaced from the longitudinal axis of the gun barrel to make the chambering of projectile more convenient, as shown in FIG. 2. The differential piston 200 has a piston head 202 with injection bores 204 journaled in a cylinder 206 and defining a liquid propellant supply chamber 206 and a combustion chamber 208. The combustion chamber vents through a port 210 into the projectile receiving chamber 212 aft of the projectile 214 and forward of the gun bolt 216. The bolt is operated by a conventional bolt operating mechanism 218 to strip the lowermost projectile from a train of projectiles 220, to chamber the projectile and to close the chamber. The combustion chamber also vents to a balancing nozzle 222 which is coaxial to the piston. A plug 224 is fixed to the piston to constrict the opening of the nozzle at the commencement of combustion. The non-coaxial arrangement of FIG. 2 develops a force couple, which may be avoided by providing two or more sets 250, 252 of pistons and balancing nozzles to provide a balance of forces with the gun barrel 254, as shown in FIG. 3. Use may be made of the scaling mechanism disclosed in Ser. No. 694,869 filed June 10, 1976 by A. R. Graham.

The differential piston 300 may be utilized as part of the balancing nozzle, as shown in FIG. 4. The piston has a piston head 302 with injection bores 304 journaled in a cylinder 306 and defining a liquid propellant supply chamber 308 and a combustion chamber 310. The piston has a piston stem 312 which is journaled in the bore 314 of a balancing nozzle 316, and has a longitudinal bore 318 running the entire length of the piston, terminating in an initial nozzle 320. The combustion chamber 310 vents forwardly through the gun barrel bore 322, and aftwardly through the piston bore 318, nozzle 320, and the balancing nozzle 314, 316. Each projectile 326 is provided with an aftwardly extending plug 328 to constrict the piston bore 318 at the commencement of combustion. In a system wherein a peak pressure of 20,000 psi is reached in the combustion chamber, the projectile does not complete the engraving of its rotating band and move significantly forward from the projectile chamber until an intermediate pressure of about 10,000 psi has been reached, The differential piston is able to slide aftwardly before that intermediate pressure has been reached, so that a progressive development of the aftward exhaust may be provided before the projectile leaves the projectile chamber. This present arrangement is an improvement over the prior known arrangement of a plug fixed to the aft end of the projectile and extending into a fixed housing balancing nozzle because the prior arrangement can only vary the nozzle throat cross-sectional area when the projectile is moving. In the present arrangement the nozzle throat area can be varied when either the piston or the projectile is moving, until they separate. Since the flow may be required to build up over a long time prior to any movement of the projectile, the present arrangement better meets this requirement than the prior arrangement did. Further, the present arrangement provides improved ballistic efficiency. The plug extends into the low pressure volume in and beyond the nozzle, reducing the cross-sectional area of the base of the projectile which is exposed to the higher pressure of the combustion chamber. Thus the initial force on the base of the projectile is lower than would be the case if chamber pressure were applied to the full area of the base. In this way the applied force can be maintained below that required to commence the translation of the projectile up the barrel, and thus prolong the period of nozzle area control. It is possible to hold the projectile stationary until peak chamber pressure is reached. Since the force on the base of the projectile increases as the plug is withdrawn from the bore of the piston, the acceleration of the projectile will increase rapidly. A fast rise in acceleration provides a higher average acceleration and thus a high projectile velocity.

The plug 400 may be fixed to the housing 402 or some other part which is stationary during the combustion period, as shown in FIG. 5. The differential piston 404 is utilized as part of the balancing nozzle. The piston has a piston head 406 with injection bore 408 journaled in a

cylinder **410** and defining a liquid propellant supply chamber **412** and a combustion chamber **414.** The piston has a piston stem **416** which is journaled in the bore **415** of a balancing nozzle **420,** and has a longitudinal bore **422** running the entire length of the piston and serving as an initial nozzle. A plurality of bores **424** communicate between the combustion chamber and the projectile chamber. The combustion chamber vents forwardly through the bores **424** and aftwardly through the piston bore **422** and the balancing nozzle **420.** The plug **400** restricts the piston bore **422** at the commencement of combustion. The cross-sectional area of the bores **424** may be used to reduce the gas pressure from the combustion chamber to the projectile chamber. For example, the combustion chamber may be permitted to peak of 50,000 psi, while the projectile chamber may be permitted a peak of 10,000 psi. The higher the pressure, the faster the rate of burning, the higher the velocity of the exhaust jet and the smaller the diameter of the exhaust jet as it passes from the balancing nozzle into the atmosphere.

The plug on the piston may be used to provide complex control of the exhaust jet as shown in FIG. 6. The differential piston **500** has a head **502** with injection bores **504** journaled in a cylinder **506** and defining a liquid propellant supply chamber **508** and a combustion chamber **510,** which lead to a chamber **512** for receiving a projectile **514.** The piston has a stem **516** which terminates in a plug **518,** and a blind bore **520** which communicates from the combustion chamber to a plurality of radial bores **522,** and is journaled in a bore **524** which terminates in a balancing nozzle **526** which has an aft constriction **528.** At the commencement of combustion the piston is in its forwardmost position and the bores **522** are closed by the wall of the bore **524.** Rearward displacement of the piston and its plug permits the increasing flow of exhaust gas out the balancing nozzle until the plug approaches the constriction **528** which decreases the flow.

It will be seen that use of the piston of displace the plug permits the exhaust flow of the balancing nozzle to be made independent of the pressure behind the projectile. The plug can control the effective open area of the balancing nozzle independently of the rapid pressure rise required in the combustion chamber. In operation, the exhaust nozzle may start from a closed condition, then have a slowly increasing area as the pressure gradually builds up, and then at a predetermined time have a rapidly decreasing area which will cause a rapidly increasing pressure buildup in the combustion chamber to provide the required acceleration of the projectile from the gun barrel without causing a sudden increase in the outflow through the balancing nozzle which would cause a blast or shock wave.

What is claimed is:

1. A gun comprising:
a gun barrel;
a combustion chamber;
a liquid propellant supply chamber;
first means having a displacement which is a time function for injecting propellant from said supply chamber into said combustion chamber as a function of said displacement;
a balancing nozzle having a throat
valve means communicating between said combustion chamber and said balancing nozzle throat for providing a conduit for the flow of combustion gas, and coupled to said first means for controlling said flow as a function of said displacement of said first means.

2. A gun according to claim **1** wherein:
said displacement of said first means is a function of the pressure of the gas in said combustion chamber.

3. A gun according to claim **1** wherein:
said first means includes a regenerative piston.

4. A gun according to claim **3** wherein:
said piston and said gun barrel are coaxial.

5. A gun according to claim **3** wherein:
said valve means includes
a longitudinal bore in said piston communicating between said combustion chamber and said nozzle throat.

6. A gun according to claim **5** wherein:
said valve means includes
a projectile disposed in said gun barrel.
a plug fixed to said projectile and extending into said piston bore which serves as a portion of said nozzle throat.
said projectile and piston having a mode of operation such that said piston is adapted to move aft away from said plug prior to said projectile moving forwardly in said gun barrel.

7. A gun according to claim **5** further including:
a housing; and
said valve means includes
a plug fixed to said housing and extending into said piston bore which serves as a portion of said nozzle throat.

8. A gun according to claim **3** wherein:
said valve means includes
a plug fixed to said piston and journaled for reciprocation within said nozzle throat and effective to change the open cross-sectional area of said nozzle throat.

9. A gun according to claim **8** wherein:
said nozzle throat has first and second constrictions which are longitudinally spaced apart,
said plug cooperating initially with said first constriction and subsequently, upon displacement by said piston, with said second constriction.

10. A gun according to claim **8** further including:
an additional combustion chamber;
said piston additionally serving to inject propellant into said additional combustion chamber;
said valve means additionally serving to communicate between said additional combustion chamber and said nozzle throat.

11. A gun according to claim **10** wherein said combustion chambers and said piston are mutually coaxial.

12. A gun according to claim **8** wherein:
said gun barrel includes a projectile receiving chamber;
means for disposing a projectile in said projectile receiving chamber;
conduit means communicating between said combustion chamber and said projectile receiving chamber for providing a flow of combustion gas.

13. A gun according to claim **12** further including:
an additional set of
combustion chamber;
liquid propellant supply chamber;
nozzle having a throat;
piston and plug;
said conduit means additionally communicating between said additional combustion chamber and said projectile receiving chamber,
said nozzle throats being mutually spaced apart and having longitudinal axes which are parallel to the longitudinal axis of said gun barrel.

14. A gun according to claim **13** wherein:
said axes of said nozzle throats and said gun barrel are substantially coplanar.

* * * * *

United States Patent [19]

Graham

[11] **4,050,348**

[45] **Sept. 27, 1977**

[54] **LIQUID PROPELLANT GUN (CONTROLLED LEAKAGE REGENERATIVE PISTON)**

[75] Inventor: **Alfred Rapp Graham,** Burnt Hills, N.Y.

[73] Assignee: **General Electric Company,** Burlington, Vt.

[21] Appl. No.: **694,866**

[22] Filed: **June 10, 1976**

[51] **Int. Cl.**^{2} **F41F 1/04**

[52] U.S. Cl. .... **89/7**; 89/1 K

[58] **Field of Search** .... 89/7, 9, 1 K; 417/349, 417/377, 381; 60/39.01

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3,138,990	6/1964	Jukes et al.	89/7
3,763,739	10/1973	Tassie	89/7

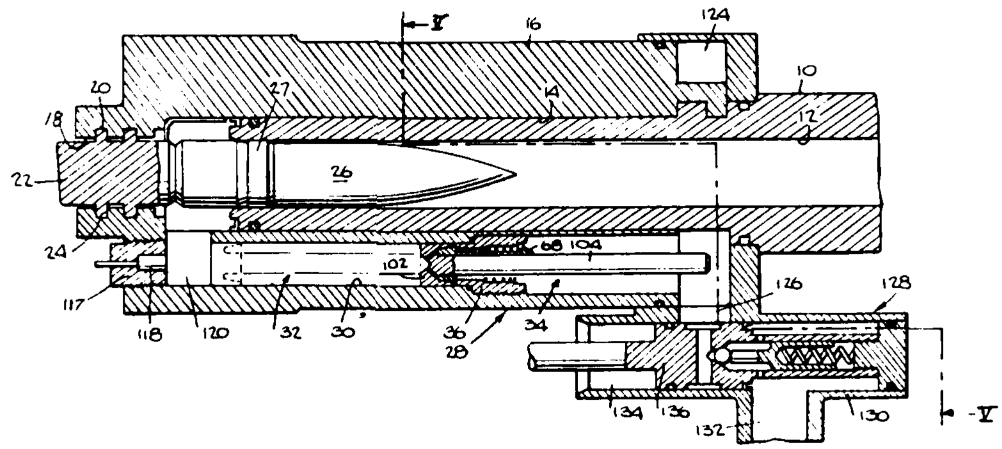
Primary Examiner—David H. Brown

Attorney, Agent, or Firm—Bailin L. Kuch

[57] **ABSTRACT**

A liquid propellant gun utilizes a differential piston having a plurality of bores through its head, which head divides the liquid propellant pumping chamber from the combustion chamber, and propellant supply means providing liquid propellant under pressure into said pumping chamber, which propellant under pressure both advances the piston to enlarge the pumping chamber and to decrease the combustion chamber and injects and atomizes a predetermined quantity of propellant through said bores from said pumping chamber into said combustion chamber.

6 Claims, 5 Drawing Figures



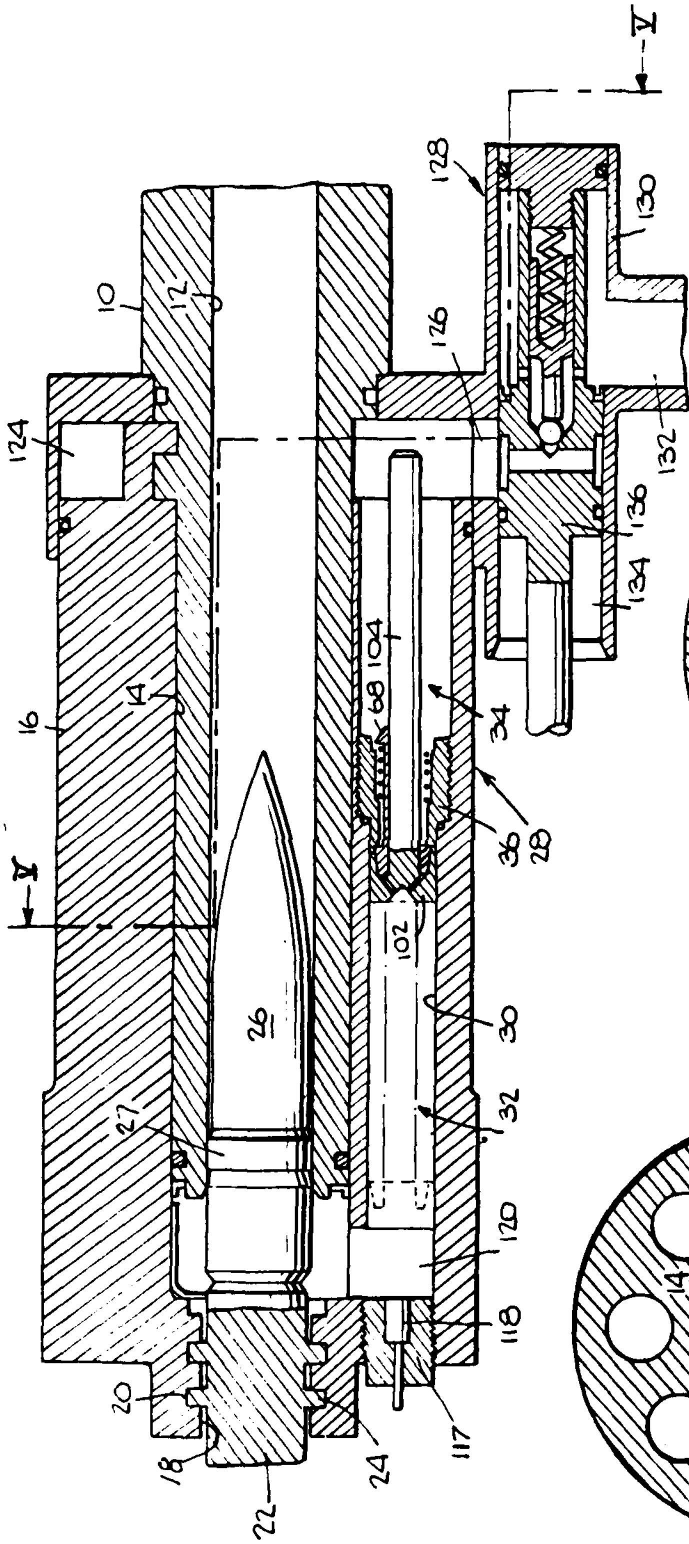


Fig. 1.

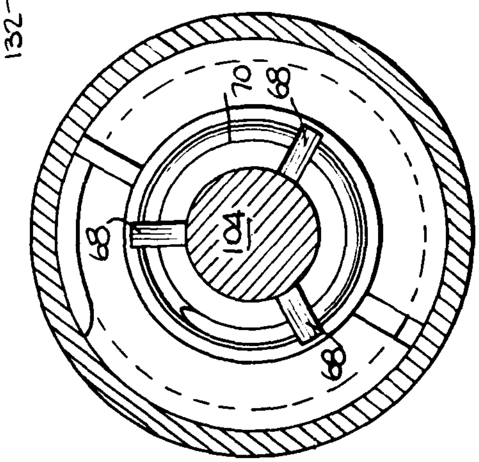


Fig. 3.

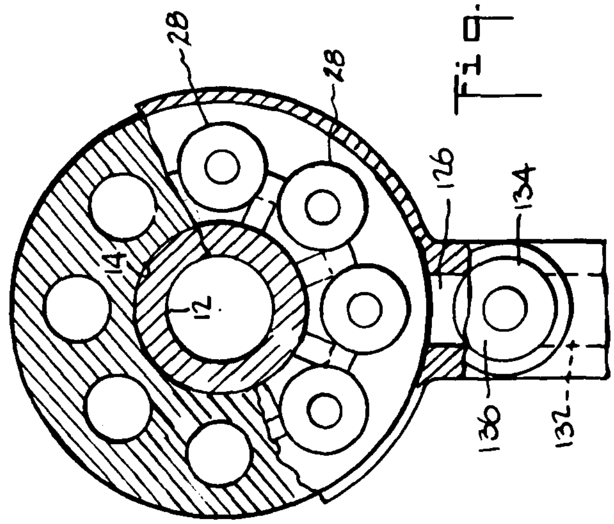


Fig. 5.

Fig.2.

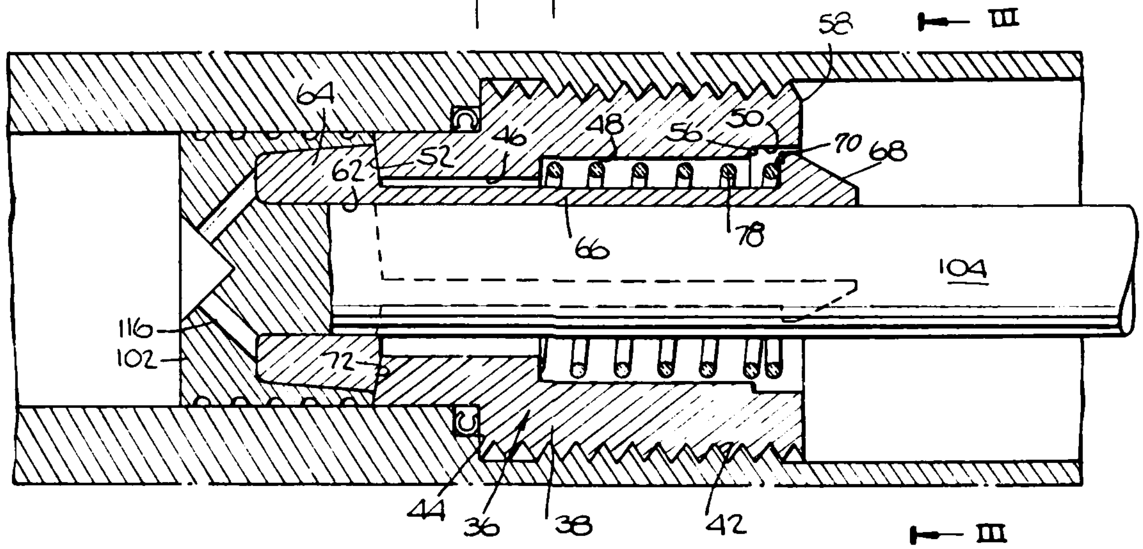

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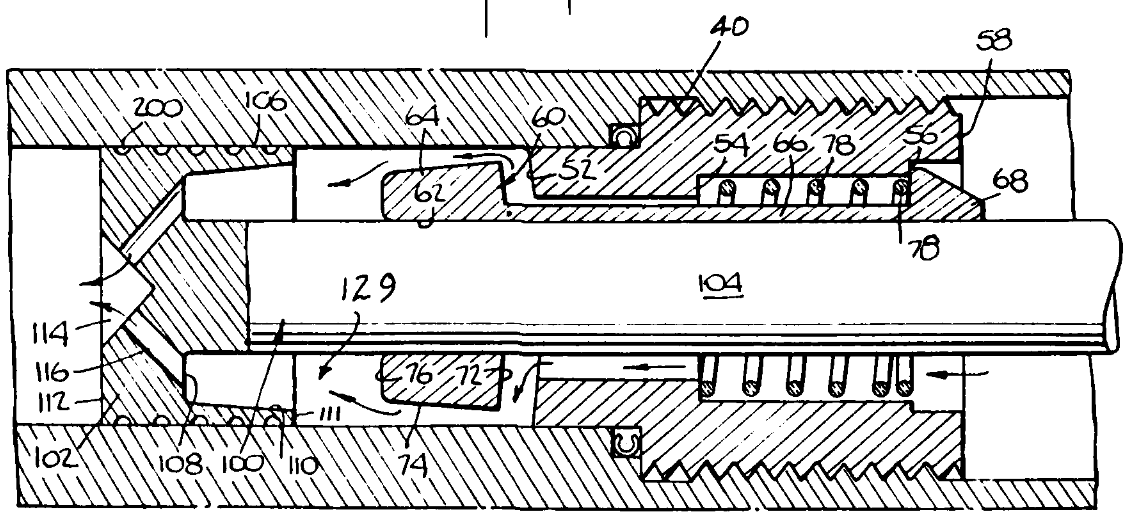
Fig.4.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UNITED STATES PATENT OFFICE

CERTIFICATE OF CORRECTION

Patent No. 4,050,348 Dated Sept. 27, 1977

Inventor(s) Alfred Rapp Graham

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

Column 3, line 12 change "gas" to --gun--; line 23 change "applied" to --applies--; line 26 change "thesurfaces" to --the surfaces--.
Column 5, line 14 change "admut" to --admit--.

Signed and Sealed this

Fourteenth Day of *February 1978*

[SEAL]

Attest:

RUTH C. MASON
Attesting Officer

LUTRELLE F. PARKER
Acting Commissioner of Patents and Trademarks

LIQUID PROPELLANT GUN (CONTROLLED LEAKAGE REGENERATIVE PISTON)

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates to liquid propellant guns utilizing a differential piston to provide continued or regenerative injection of propellant into the combustion chamber after initial ignition of propellant in the chamber.

2. Prior Art

Liquid propellant guns utilizing differential pistons to pump propellant into the combustion chamber during combustion are now well know. Early work is described in a Final Report of Nov. 19, 1953—Jan. 31, 1956 under contract DA-36-034-ORD-1504RD, Project TS1-47-8 by V. M. Barnes, Jr. et al which apparently in part corresponds to Jukes et al., U.S. Pat. No. 3,138,990 filed Oct. 9, 1961; in a report No. 17-2 of June 15, 1954 under contract NOrd-10448 by C. R. Foster el at; and in a Final Report of Sept. 1, 1957 under contract NOrd 16217, Task 1, by L. C. Elmore et al. Other patents of interest are J. W. Treat, Jr., U.S. Pat. No. 2,922,341, filed Nov. 7, 1955; E. J. Wilson, Jr. et al., U.S. Pat. No. 2,981,153, filed Nov. 14, 1952; C. M. Hudson, U.S. Pat. No. 2,986,072, filed Nov. 19, 1952; and E. J. Vass, et al., U.S. Pat. No. 3,690,255 filed Oct. 1, 1970.

An object of this invention is to provide an improved liquid propellant gun having a combustor assembly utilizing a differential piston wherein a uniform metered quantity of atomized propellant may be passed into the combustion chamber to serve as a primer without additional valves in said piston.

A second object of the invention is to avoid the complexity of providing a means for retaining propellant behind the piston during the filling operation by simply allowing said propellant to "leak" through the piston into the combustion chamber for purposes described under the first object of the invention.

A feature of this invention is the provision of a liquid propellant gun utilizing a differential piston having a plurality of bores through its head, which head divides the liquid propellant pumping chamber from the combustion chamber, and propellant supply means providing liquid propellant under fixed feed pressure into said pumping chamber, which propellant under pressure both advances the piston to enlarge the pumping chamber and to decrease the combustion chamber while increasing pressure in said combustion chamber and injects and atomizes a predetermined quantity of propellant through said bores from said pumping chamber into said combustion chamber to serve as a primer.

RELATED CASE

Subject matter directed to the details of the check valve disclosed herein is claimed in the Application of D. P. Tassie, Ser. No. 694,867 filed concurrently herewith, on June 10, 1976.

BRIEF DESCRIPTION OF THE DRAWING

These and other objects, advantages and features of the invention will be apparent from the following specification thereof taken in conjunction with the accompanying drawing in which:

FIG. 1 is a detail view in longitudinal cross-section of a gun incorporating a combustor assembly embodying this invention;

FIG. 2 is an enlarged detail of FIG. 1 of the combustor assembly in the end of propellant injection mode;

FIG. 3 is a transverse view in cross-section taken along the plane III—III of FIG. 2;

FIG. 4 is an enlarged detail of FIG. 1 of the combustor assembly in the propellant filling mode: and

FIG. 5 is a transverse view in cross-section of a gun incorporating a plurality of the combustor assemblies of FIG. 1 taken along the folded plane V—V.

DESCRIPTION OF THE PREFERRED EMBODIMENT

This invention, as shown in FIG. 1, may be incorporated in a liquid propellant gun of the type shown by D. P. Tassie in U.S. Pat. No. 3,763,739. However, the invention as here shown utilizes a monopropellant, although the regenerative piston system is applicable to bipropellants as well.

The gun system includes a gun barrel **10**, having a gun bore **12**, which is fixed in a forward bore **14** of a housing **16**. The housing has an aft bore **18**, with a plurality of locking recesses **20**, which receives a gun bolt **22** having a plurality of locking lugs **24**. A projectile **26** having a rotating band **27** may be inserted through the aft bore **18** and pushed forwardly into the gun bore **12** by the bolt **22**, which bolt is then locked in and to the housing. The band **27** makes a gas tight seal with the bore.

The housing **16** may have one, or as shown in FIG. **5**, a plurality of combustor assemblies **28**. As shown in FIGS. **1**, **2** and **4**, each combustor assembly includes a longitudinal bore **30** having a combustion chamber portion **32** and a liquid propellant inlet chamber portion **34**. A coaxial check valve **36** is fixed in the bore **30** and includes an outer annular housing **38** which is externally threaded at **40** to engage threads **42** and a shoulder **44** in the bore **30**, and has a longitudinal bore in three stepped portions: a portion **46** having the smallest diameter, a portion **48** having an intermediate diameter, and a portion **50** having the largest diameter. The housing **38** has a left face **52**, an internal shoulder **54**, an internal shoulder **56**, and a right face **58**. A sleeve **60** has an longitudinal bore **62**, a left, truncated conical, annular portion **64**, an intermediate portion provided by a plurality (here shown as three) of longitudinally extending, circumferentially spaced apart, beams **66**, and a right portion provided a like plurality of heel, enlarged terminations **68** on each beam. The right portion has a left face **70** which will abut the shoulder **56**, the left portion has a right face **72** which will mate with and will seal against the face **52**, a conical, peripheral face **74**, and a left face **76**. A helical compression spring **78** is disposed between the shoulder **54** and the face **70** and biases the sleeve **60** to the right.

A piston **100** has a head portion **102** which slides in the combustion chamber portion **32** and a stem portion **104** which slides in the bore **62** of the sleeve **60**. The head portion has an L-ring longitudinal cross-section with an outer-peripheral surface **106** for sliding engagement with the wall of the chamber **32**, a right transverse annular surface **108** which will mate with and will seal against the face **76**, a right conical annular surface **110** which will mate with and will seal against the face **74**, a transverse face which will mate with and will seal against the face **52**, a left face **112** having a conical recess **114**, and a plurality of bores **116** disposed in an annular row and interconnecting the face **108** with the recess **114**. Alternatively, these bores may be arranged as axial bores and in other configurations.

The left end of the combustion chamber **32** is closed by a plug **117** which carries a spark plug **118**. A respective radial bore **120** communicates between the respective combustion chamber **32** and the left end of the bore **12**.

The right end of each liquid propellant inlet chamber portion **34** opens into an annular passageway or manifold **124**, which in turn is open, at **126**, to a propellant supply valve **128**. The valve includes a housing **130** having an inlet port **132**, a cylinder **134**, and a spool **136**. The spool may be cam controlled, as shown in U.S. Pat. No. 3,763,739, for synchronization with the other gas functions.

As shown in FIG. **1**, before loading, the valve **128** is closed and the piston **100** is in its righthandmost position wherein it is nested with and sealed to the check valve **36**. A projectile **26** is inserted into the gun bore **12** and the bolt **22** is closed and locked. The spool **136** is shifted to the left, opening the valve **128**, admitting liquid propellant under pressure into the manifold **124**. Propellant under pressure passes into the chamber portion **34** and into the longitudinal recesses between the beams **68**, and applied pressure against the surface **72** of the portion **64** to shift the portion, against the bias of the spring **78**, away from the surface **52**, to permit the flow of liquid propellant around the portion **64** and against thesurfaces **108** and **110** of the head **102** of the piston. This pressure provided by the incoming liquid propellant pushes the piston head to the left, creating and enlarging the available volume of a propellant pumping chamber portion **129** and decreasing the available volume of the combuston chamber portion. A small quantity of the liquid propellant passes through the bores **116** into the combustion chamber portion during this shifting of piston head, and thus a quantity of air which had entered when the bolt was open, plus this quantity of liquid propellant, are compressed and trapped in the combustion chamber. The liquid propellant is atomized as it passes through the bores, and the total quantity and the size of the droplets is a function, inter alia, of the diameter of the bores, the configuration of the bores such as axial or impinging (FIG. **4**), and the pressure of the liquid propellant. When the piston head has reached its maximum excursion in compression, that is, leftmost travel, the liquid pressure in the pumping chamber portion **129** equals the liquid pressure in the supply manifold **124** and the supply chamber portion **34**, and the spring **78** drives the sleeve **60** to the right, thereby closing the check valve **36**. This quantity of compressed air and atomized propellant in the combustion chamber portion adjacent the sparkplug is predetermined and repeatable, and serves as a primer for the combustion of the main charge of propropellant disposed in the supply chamber portion. Ignition of this primer is provided by the sparkplug. Ignition of the primer generates combustion gas whose pressure drives the piston to the right to increase the volume of the combustion chamber portion and to decrease the volume of the pumping chamber portion. The difference in areas of the two faces of the piston generates a difference in pressure in the two chambers so that liquid propellant is continually forced through the bores **116** into the combustion chamber at a controlled rate. The piston head is displaced continually to the right towards the closed check valve **36**. As the piston head closes onto the annulus **74** of the check valve the remainder of the liquid propellant trapped therebetween provides an energy absorbing function and absorbs the energy of the moving piston head as it

impacts against the check valve annulus, without any ullage. The interface surfaces **110** and **74** should be conical, approaching a cylinder, to provide maximum travel time for trapped fluid to absorb energy and pass through the bores, yet not so cylindrical as to trap liquid and prevent such liquid from reaching and passing through the bores.

The interface between the piston stem **104** and the bore **62** may be without seals, since any leakage from the pumping chamber portion will merely pass back into the supply chamber portion. The L-ring section **106** provides an effective seal between the hot gun gas in the combustion chamber and the relatively cold liquid in the pumping chamber portion, in that there is a difference in pressure on the piston head which provides for the flow of liquid propellant from the pumping chamber to the combustion chamber, which precludes any flow of gun gas from the combustion chamber to the pumping chamber.

To provide lubrication between the piston head **102** and the wall of the bore **30**, a plurality of shallow, helical grooves **200** may be provided in the peripheral surface of the piston head, communicating from the left face **112** to the right face, adjacent **110**. Liquid propellant will be forced through these apertures at the same time as through the bores **116**, and will lubricate this interface. All lubricant passing into the combustion chamber portion will be in a swirl pattern, thus providing a film cooling effect to the chamber bore **30**, after which it will be burned, either as primer, or as part of the main charge. A fresh supply of lubricant is provided during each firing cycle, and will clean out any particles which may lodge in the grooves.

Lubrication of the interface between the piston stem and the check valve sleeve is also provided by the liquid propellant.

The leakage propellant will act as a booster as well as a primer. The piston compresses air in front of it, and then creates a two-phase mixture in front of it, which on ignition, acts as a booster charge. A small booster charge results in a much faster initial chamber pressure rise which improves ballistic efficiency.

What is claimed is:

1. A liquid propellant, regenerative action, gun comprising:
   - a cylinder having a longitudinal bore;
   - a regenerative piston having a head disposed within and circumferentially sealed to said cylinder bore;
   - said piston head
     - dividing said cylinder bore into a combustion chamber portion and a propellant pumping chamber portion,
     - having a combustion face defining in part said combustion chamber portion and a supply face defining in part said propellant pumping chamber portion, and
     - having a plurality of bores communicating between said supply face and said combustion face;
   - igniter means disposed within said combustion chamber portion;
   - means for admitting a quantity of gas into said combustion chamber portion;
   - means for supplying liquid propellant under pressure;
   - supply valve means for coupling and for decoupling said supply means to said propellant pumping chamber portion of said cylinder bore;

said piston, said gas admitting means, said supply valve means and said igniter means having a mode of operation such that:

initially said piston is so disposed within said cylinder bore as to provide said pumping chamber portion with substantially zero volume and said combustion chamber portion with its maximum volume,

thereafter said gas admitting means admits a quantity of gas into said combustion chamber portion; and

thereafter said supply valve means couples said supply means to said propellant pumping chamber portion to admut a first quantity of propellant under pressure into said pumping chamber portion, which admission causes translation of said piston head to increase the volume of said pumping chamber portion and to decrease the volume of said combustion chamber and also causes the passage of a lesser second quantity of propellant from said pumping chamber through said plurality of bores in said piston head into said combustion chamber, said plurality of bores serving to atomize such passed propellant into droplets, whereby said quantity of gas and said second quantity of atomized propellant are compressed in said combustion chamber portion adjacent said igniter means and serve as a primer to be ignited by said igniter means.

2. A gun according to claim 1 wherein:

the opening and closing of said projectile receiving chamber by said gun bolt serves to admit and trap a quantity of air in said combustion chamber portion, which air is compressed subsequently by said piston head while liquid propellant passes through said bores of said piston head, to provide a two phase mixture of gas and atomized liquid propellant in said combustion chamber portion.

3. A gun according to claim 1 wherein:

said piston head has a peripheral surface which engages the inner wall of said cylinder bore, and

a groove is provided in said piston head peripheral surface communicating from said supply face to said combustion face of said piston head, whereby when said valve means couples said supply means to said propellant pumping chamber portion and liquid propellant under pressure enters said propellant pumping chamber portion, a portion of such liquid propellant passes through said groove in said piston head peripheral surface and serves as a lubricant for the interface of said piston head peripheral surface and said cylinder bore inner wall, as well as a film coolant to said cylinder bore inner wall.

4. A gun according to claim 3 wherein:

said groove comprises one of a plurality of helically extending, annularly spaced apart grooves.

5. A process of charging a liquid propellant gun having a differential piston with propellant injection bores therethrough for regenerative injection of propellant into the combustion chamber from a propellant pumping chamber, wherein said piston interfaces both said combustion chmber and said pumping chamber, comprising:

translating said piston to provide said pumping chamber with substantially zero volume and said combustion chamber with its maximum volume;

admitting liquid propellant under pressure into said pumping chamber to translate said piston to increase the available volume of the pumping chamber and to decrease the volume of the combustion chamber and to concurrently force a quantity of propellant from said pumping chamber through said injection bores and atomizing said quantity of propellants into droplets and into said combustion chamber.

6. A process according to claim 5 further including:

admitting a second quantity of gas into said combustion chamber;

compressing said gas and said droplets into a two phase mixture.

* * * * *

United States Patent [19]

Graham

[11] **4,050,349**

[45] **Sept. 27, 1977**

[54] **LIQUID PROPELLANT GUN (SCALING WITH MULTIPLE COMBUSTION ASSEMBLIES)**

[75] Inventor: **Alfred Rapp Graham**, Burnt Hills, N.Y.

[73] Assignee: **General Electric Company**, Burlington, Vt.

[21] Appl. No.: **694,869**

[22] Filed: **June 10, 1976**

[51] **Int. Cl.**[2] **F41F 1/04**

[52] **U.S. Cl.** **89/7**

[58] **Field of Search** .... 89/7, 9, 1 K; 417/349, 417/377, 381; 60/39.01

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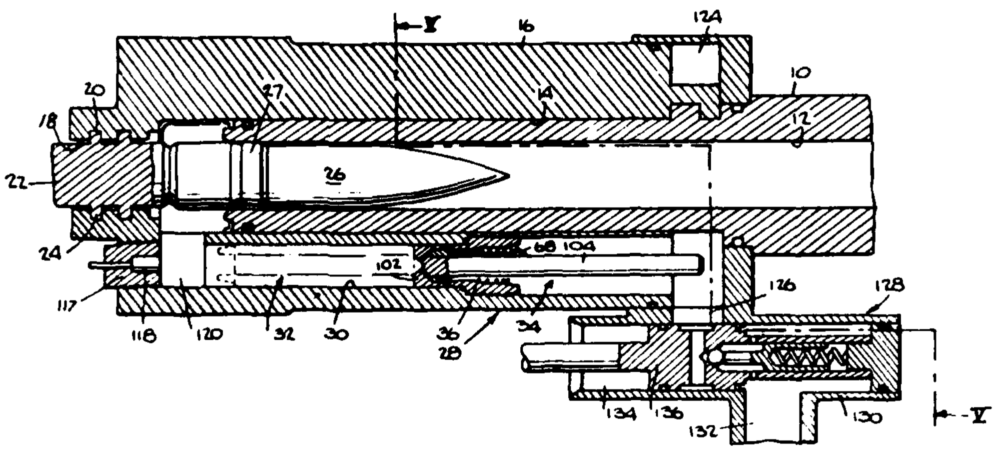
Primary Examiner—David H. Brown

Attorney, Agent, or Firm—Bailin L. Kuch

[57] **ABSTRACT**

A liquid propellant gun utilizes a plurality of combustor assemblies or cells located about the periphery of the breech end of a gun barrel. Scaling to larger size guns may be achieved by using different numbers of identical combustor assemblies about the periphery of the bore. Further adjustments may be made by changing the stroke length. Such a standardized piston may be developed for a single cell gun where it may be perfected prior to adding pluralities of said cells to form larger guns. Due to each cell burning propellant progressively, each generates gas at a fixed rate so that for example eight cells supply eight times the rate of one cell. Hence scaling becomes a rational procedure.

2 Claims, 5 Drawing Figures



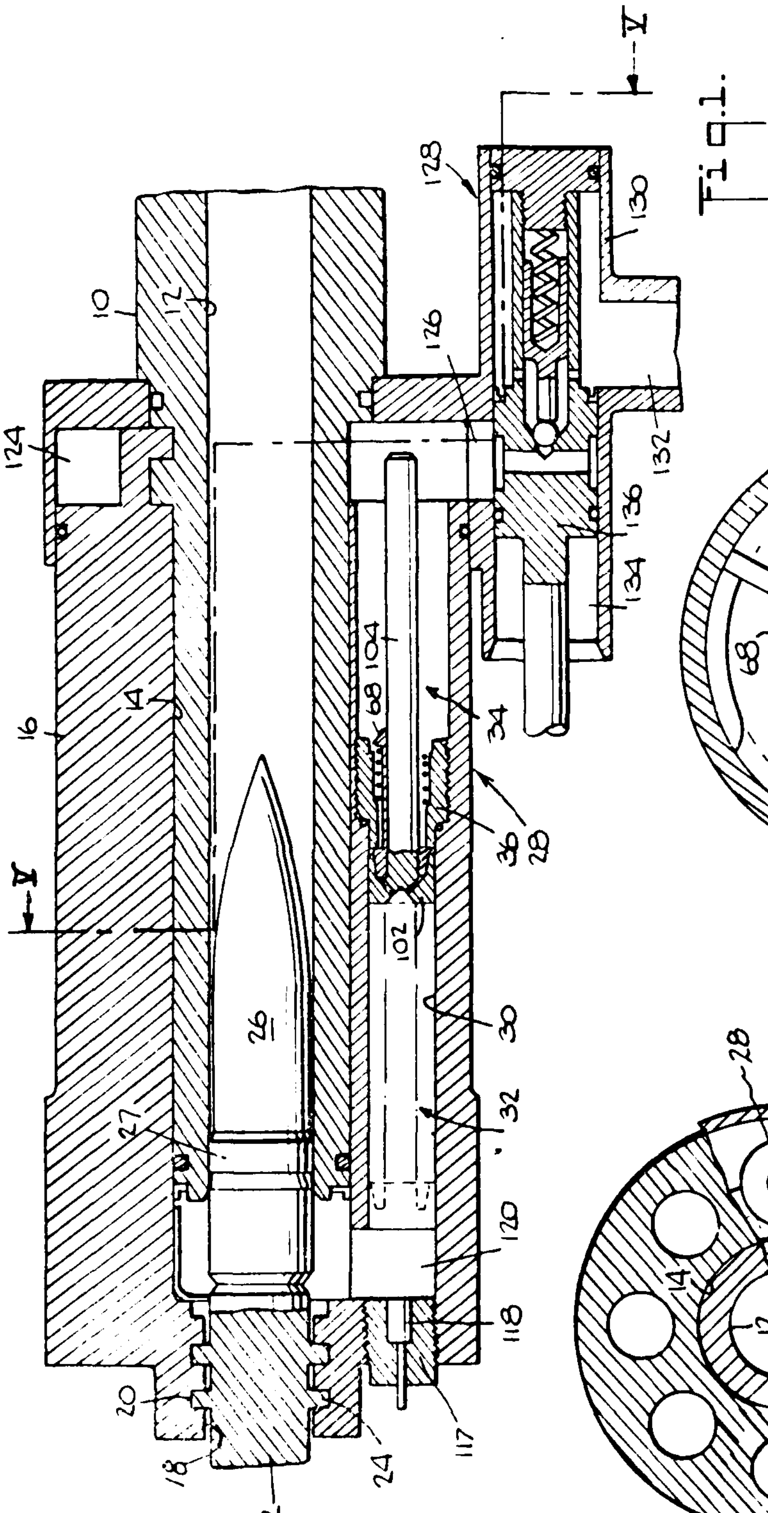


Fig. 1.

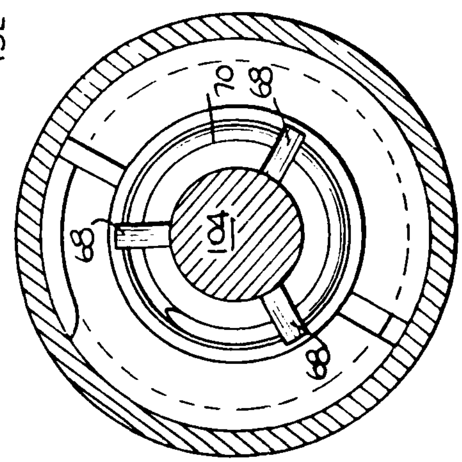


Fig. 3.

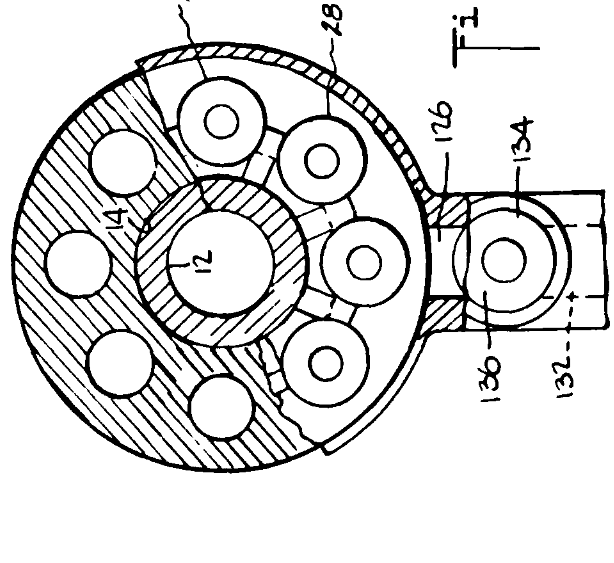


Fig. 5.

Fig. 2.

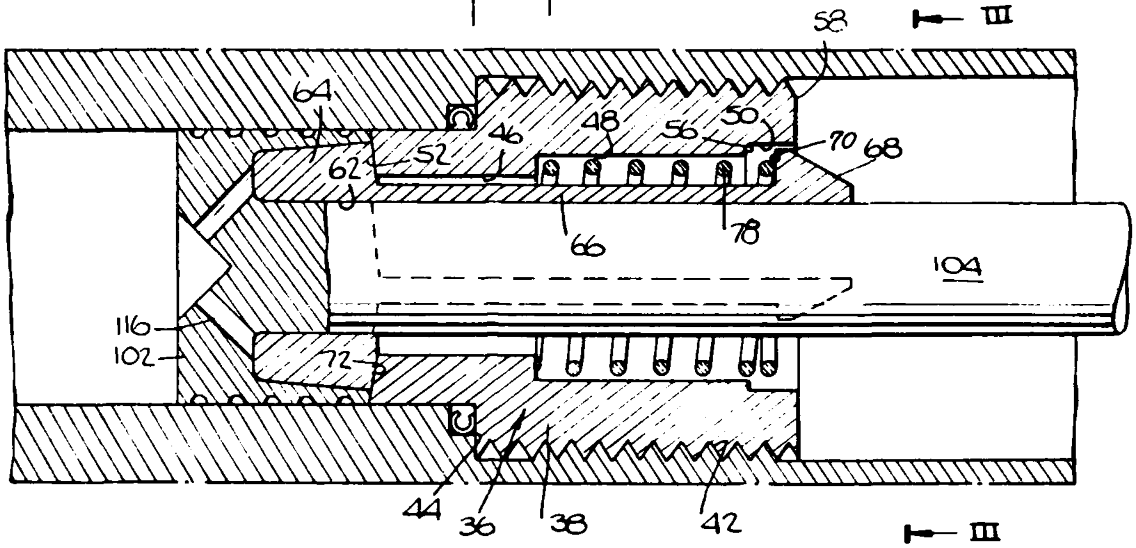

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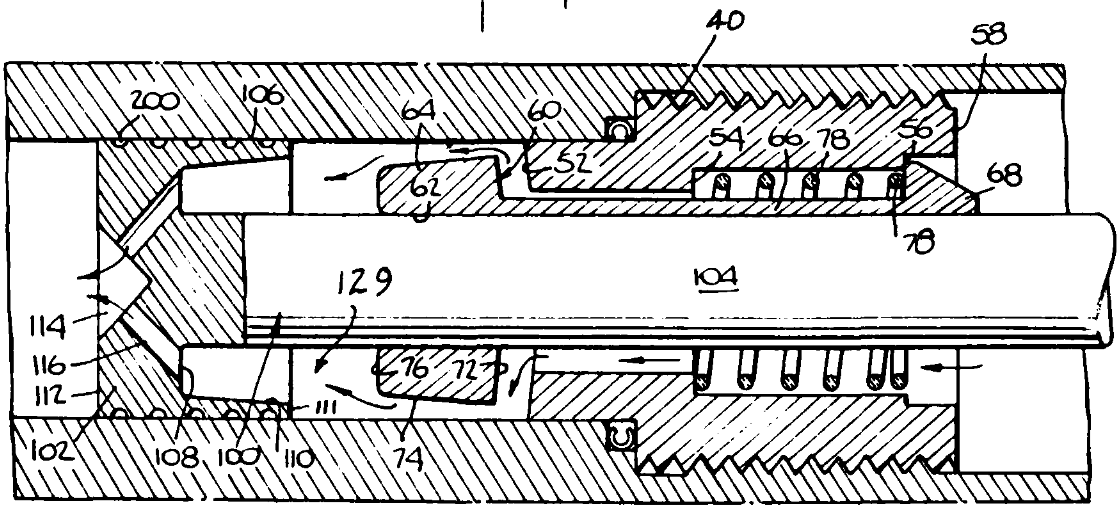
Fig. 4.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UNITED STATES PATENT OFFICE

CERTIFICATE OF CORRECTION

Patent No. 4,050,349 Dated Sept. 27, 1977

Inventor(s) Alfred Rapp Graham

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

Column 2, line 30 change "39" to --38--.
Column 3, line 39 change "then" to --the--.
Column 4, line 45 change "storke" to --stroke--.

Signed and Sealed this

Fourteenth **Day of** *March 1978*

[SEAL]

Attest:

RUTH C. MASON
Attesting Officer

LUTRELLE F. PARKER
Acting Commissioner of Patents and Trademarks

LIQUID PROPELLANT GUN (SCALING WITH MULTIPLE COMBUSTION ASSEMBLIES)

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates to liquid propellant guns utilizing a differential piston to provide continued or regenerative injection of propellant into the combustion chambers after initial ignition of propellant in the chamber.

2. Prior Art

Liquid propellant guns utilizing differential pistons to pump propellant into the combustion chamber during combustion are now well known. Early work is described in a Final Report of Nov. 19 53—31 Jan. 56 under contract DA-36-034-ORD-1504RD, Project TSI-47-8 by V. M. Barnes, Jr. et al which apparently in part corresponds to Jukes et al, U.S. Pat. No. 3,138,990 filed Oct. 9, 1961; in a report No. 17-2 of June 15, 1954 under contract NOrd-10448 by C. R. Foster et al; and in a Final Report of Sept. 1, 1957 under contract NOrd 16217, Task 1, by L. C. Elmore et al. Other patents of interest are J. W. Treat, Jr., U.S. Pat. No. 2,922,341, filed Nov. 7, 1955; E. J. Wilson, Jr. et al, U.S. Pat. No. 2,981,153, filed Nov. 14, 1952; C. M. Hudson, U.S. Pat. No. 2,986,072, filed Nov. 19, 1952; and E. J. Vass et al, U.S. Pat. No. 3,690,255 filed Oct. 1, 1970.

An object of this invention is to provide a rational scaling procedure through the use of a plurality of identical combustor assemblies utilizing a differential piston, such combustor assemblies being of a standardized design fully developed through test, therefore allowing any practical number of said combustor assemblies to supply gas to various size guns.

A feature of this invention is the provision that a standardized combustor assembly may be fully developed to a high degree of reliability before using these modules in various size multicell guns. Two or possibly three different size pistons may be required to cover a complete range of gun bores.

RELATED CASES

Subject matter directed to the details of the check valve disclosed herein is claimed in Ser. No. 694,867 filed by D. P. Tassie on June 10, 1976, and in Ser. No. 694,868 filed by A. R. Grahm on June 10, 1976. Subject matter directed to the details of the combustor assembly disclosed herein is claimed in Ser. No. 694,866 filed by A. R. Grahm on June 10, 1976.

BRIEF DESCRIPTION OF THE DRAWING

These and other objects, advantages and features of the invention will be apparent from the following specification thereof taken in conjunction with the accompanying drawing in which:

FIG. 1 is a detail view in longitudinal cross-section of a gun incorporating a combustor assembly embodying this invention;

FIG. 2 is an enlarged detail of FIG. 1 of the combustor assembly in the end of propellant injection mode;

FIG. 3 is a transverse view in cross-section taken along the plane III—III of FIG. 2;

FIG. 4 is an enlarged detail of FIG. 1 of the combustor assembly in the propellant filling mode; and

FIG. 5 is a transverse view in cross-section of a gun incorporating a plurality of the combustor assemblies of FIG. 1 taken along the folded plane V—V.

DESCRIPTION OF THE PREFERRED EMBODIMENT

This invention, as shown in FIG. 1, may be incorporated in a liquid propellant gun of the type shown by D. P. Tassie in U.S. Pat. No. 3,763,739. However, the invention as here shown utilizes a monopropellant, although the regenerative piston system is applicable to bipropellants as well.

The gun system includes a gun barrel **10**, having a gun bore **12**, which is fixed in a forward bore **14** of a housing **16**. The housing has an aft bore **18**, with a plurality of locking recesses **20**, which receives a gun bolt **22** having a plurality of locking lugs **24**. A projectile **26** having a rotating band **27** may be inserted through the aft bore **18** and pushed forwardly into the gun bore **12** by the bolt **22**, which bolt is then locked in and to the housing. The band **27** makes a gas tight seal with the bore.

The housing **16** may have one, or as shown in FIG. **5**, a plurality of combustor assemblies **28**. As shown in FIGS. **1**, **2** and **4**, each combustor assembly includes a longitudinal bore **30** having a combustion chamber portion **32** and a liquid propellant inlet chamber portion **34**. A coaxial check valve **36** is fixed in the bore **30** and includes an outer annular housing **38** which is externally threaded at **40** to engage threads **42** and a shoulder **44** in the bore **30**, and has a longitudinal bore in three stepped portions: a portion **46** having the smallest diameter, a portion **48** having an intermediate diameter, and a portion **50** having the largest diameter. The housing **39** has a left face **52**, an internal shoulder **54**, an internal shoulder **56**, and a right face **58**. A sleeve **60** has a longitudinal bore **62**, a left, truncated conical, annular portion **64**, an intermediate portion provided by a plurality (here shown as three) of longitudinally extending, circumferentially spaced apart, beams **66**, and a right portion provided a like plurality of heel, enlarged terminations **68** on each beam. The right portion has a left face **70** which will abut the shoulder **54**, the left portion has a right face **72** which will mate with and will seal against the face **52**, a conical, peripheral face **74**, and a left face **76**. A helical compression spring **78** is disposed between the shoulder **54** and face **70** and biases the sleeve **60** to the right.

A piston **100** has a head portion **102** which slides in the combustion chamber portion **32** and a stem portion **104** which slides in the bore **62** of the sleeve **60**. The head portion has an L-ring longitudinal cross-section with an outer-peripheral surface **106** for sliding engagement with the wall of the chamber **32**, a right transverse annular surface **108** which will mate with and will seal against the face **76**, a right conical annular surface **110** which will mate with and will seal against the face **74**, a transverse face **111** which will mate with and seal against the face **52**, a left face **112** having a conical recess **114**, and a plurality of bores **116** disposed in an annular row and interconnecting the face **108** with the recess **114**.

The left or gas outlet end of the combustion chamber **30** of each combustor assembly **28** is closed by a plug **117** which carries a spark plug **118**. A respective radial bore **120** communicates between the respective combustion chamber **30** and the left end of the bore **12** adjacent the aft end of the projectile **26**, or projectile receiving chamber.

The right or inlet end of each liquid propellant inlet chamber portion **34** of each combustor assembly opens into an annular passageway or manifold **124**, which in

turn is open, at 126, to a propellant supply valve 128. The valve includes a housing 130 having an inlet port 132, a cylinder 134, and a spool 136. The spool may be cam controlled, as shown in U.S. Pat. No. 3,763,739, for synchronization with the other gun functions. Although a single tier of eight combustor assemblies is shown, other configurations such as double or triple tiers, and other convenient arrangements may be employed and are thus not limited to the single tier configuration of FIG. 3.

As shown in FIG. 1, before loading, the valve 128 is closed and the piston 100 is in its righthandmost position wherein it is nested with and sealed to the check valve 36. A projectile 26 is inserted into the gun bore 12 and the bolt 22 is closed and locked. The spool 136 is shifted to the left, opening the valve 128, admitting liquid propellant under pressure into the manifold 124. Propellant under pressure passes into the chamber portion 34 and into the longitudinal recesses between the beams 66, and applies pressure against the surface 72 of the portion 64 to shift the portion, against the bias of the spring 78, away from the surface 52, to permit the flow of liquid propellant around the portion 64 and against the surfaces 108 and 110 of the head 102 of the piston. This pressure provided by the incoming liquid propellant pushes the piston head to the left, creating and enlarging the available volume of a propellant pumping chamber portion 129 and decreasing the available volume of the combustion chamber portion. A small quantity of the liquid propellant passes through the bores 116 into the combustion chamber portion during this shifting of piston head, and thus a quantity of air which had entered when the bolt was open, plus this quantity of liquid propellant, are compressed and trapped in the combustion chamber. The liquid propellant is atomized as it passes through the bores, and the total quantity and the size of the droplets is a function, inter alia, of the diameter of the bores, the velocity of the piston and the pressure of the liquid propellant. When then piston head has reached its maximum excursion in compression, that is, leftmost travel, the liquid pressure in the pumping chamber portion 129 equals the liquid pressure in the supply manifold 124 and the supply chamber portion 34, and the spring 78 drives the sleeve 60 to the right, thereby closing the check valve 36. This quantity of compressed air and atomized propellant in the combustion chamber portion adjacent the sparkplug is predetermined and repeatable, and serves as a primer for the combustion of the main charge of propellant disposed in the supply chamber portion. Ignition of this primer is provided by the sparkplug. Ignition of the primer generates combustion gas whose pressure drives the piston to the right to increase the volume of the combustion chamber portion and to decrease the volume of the pumping chamber portion. The difference in areas of the two faces of the piston generates a difference in pressure in the two chambers so that liquid propellant is continually forced through the bores 116 into the combustion chamber at a controlled rate. The piston head is displaced continually to the right towards the closed check valve 36. As the piston head closes onto the annulus 74 of the check valve the remainder of the liquid propellant trapped therebetween provides an energy absorbing function and absorbs the energy of the moving piston head as it impacts against the check valve annulus, without any ullage. The interface surfaces 110 and 74 should be conical, approaching a cylinder, to provide maximum travel time for trapped fluid to absorb energy and pass through the bores, yet not so cylindrical as to trap liquid and prevent such liquid from reaching and passing through the bores.

The interface between the piston stem 104 and the bore 62 may be without seals, since any leakage from the pumping chamber portion will merely pass back into the supply chamber portion. The L-ring section 106 provides an effective seal between the hot gun gas in the combustion chamber and the relatively cold liquid in the pumping chamber portion, in that there is a difference in pressure on the piston head which provides for the flow of liquid propellant from the pumping chamber to the combustion chamber, which precludes any flow of gun gas from the combustion chamber to the pumping chamber.

To provide lubrication between the piston head 102 and the wall of the bore 32, a plurality of shallow, helical grooves 200 may be provided in the peripheral surface of the piston head, communicating from the left face 112 to the right face, adjacent 110. Liquid propellant will be forced through these apertures at the same time as through the bores 116, and will lubricate this interface. All lubricant passing into the combustion chamber portion will be in a swirl pattern, ensuring good mixing, and will be burned, either as primer, or as part of the main charge. A fresh supply of lubricant is provided during each firing cycle, and will clean out any particles which may lodge in the grooves.

Lubrication of the interface between the piston stem and the check valve sleeve is also provided by the liquid propellant.

The leakage propellant will act as a booster as well as a primer. The piston compresses air in front of its, and then creates a two-phase mixture in front of it, which on ignition, acts as a booster charge. A small booster charge results in a much faster initial chamber pressure rise which improves ballistic efficiency.

This scaling concept may be best understood by illustration. Assume that a combustor assembly or cell has been developed such that six such cells provide the necessary gas supply to fire a 3 inch gun. A 4 inch gun having the same charge to mass ratio would require exactly $(4\text{ inch}/3\text{ inch})^2 \times 6$ cells $= 10.67$ cells. One would select 10 cells and increase the storke length slightly to make up for the "0.67" not accounted for. Likewise a 5 inch gun would require 16 cells. As many cells may be used as desired, but at this point one might consider a second size cell to cover the 5 to 10 inch range. Clearly the charge to mass ratio may be changed for a given size gun bore by varying the number of cells or stroke length.

By developing two or three standard combustor assemblies it is possible to cover all gun sizes of interest. It is possible to develop such standard combustor assemblies to a high degree of reliability, and in an economical manner, since basic development will be accomplished in a single cell type fixture or gun. Each piston developed will employ a maximum length piston stem operating at the maximum piston velocity to be expected under any condition since this represents a limiting condition from the damping standpoint.

In order to employ such a piston for smaller propellant charges, the stroke length is changed by shortening the piston stem and supply chamber by equivalent amounts.

It is desirable to journal the pistons 100 for reciprocation along respective axes which are parallel to the axis

of the gun bore, thereby precluding any side fictional loading of the pistons during gun recoil.

What is claimed is:

1. A liquid propellant gun comprising:

a gun barrel having a bore and a projectile receiving chamber, both disposed along a first longitudinal axis;

an annular row of a plurality of combustor assemblies, each respectively comprising a liquid propellant supply chamber, a combustion chamber and a regenerative piston for pumping liquid propellant from said supply chamber into said combustion chamber, each respectively disposed along a respective one of a like plurality of second longitudinal axes, said second longitudinal axes being uniformly spaced apart, parallel to each other and to said first longitudinal axis and uniformly spaced from said first longitudinal axis, each of said plurality of combustion chamber also including a respective one of a like plurality of igniter means; and

conduit means coupling each of said combustion chambers to said projectile receiving chamber for transmitting combustion gas from each said combustion chamber to said projectile receiving chamber.

2. A gun according to claim 1 wherein:

said plurality of combustor assemblies is equal to or greater than three in number.

* * * * *

United States Patent [19]

Tassie

[11] **4,050,352**

[45] **Sept. 27, 1977**

[54] **RENEWABLE LIQUID INVESTMENT SEAL**

[75] Inventor: **Douglas Pray Tassie,** St. George, Vt.

[73] Assignee: **General Electric Company,** Burlington, Vt.

[21] Appl. No.: **668,546**

[22] Filed: **Mar. 19, 1976**

[51] **Int. Cl.**² **F41F 1/04**

[52] **U.S. Cl.** **89/7;** 89/26

[58] **Field of Search** 89/7, 26; 102/92-94

[56] **References Cited**

U.S. PATENT DOCUMENTS

407,890	7/1889	Day	102/92
440,672	11/1890	Wesson	102/92
539,733	5/1895	Gerdom	89/26
1,031,320	7/1912	Brown	102/92
1,036,171	8/1912	Ackerman	102/92
2,942,525	6/1960	Gillman	89/26
3,356,029	12/1967	Seidel	102/92
3,763,739	10/1973	Tassie	89/7

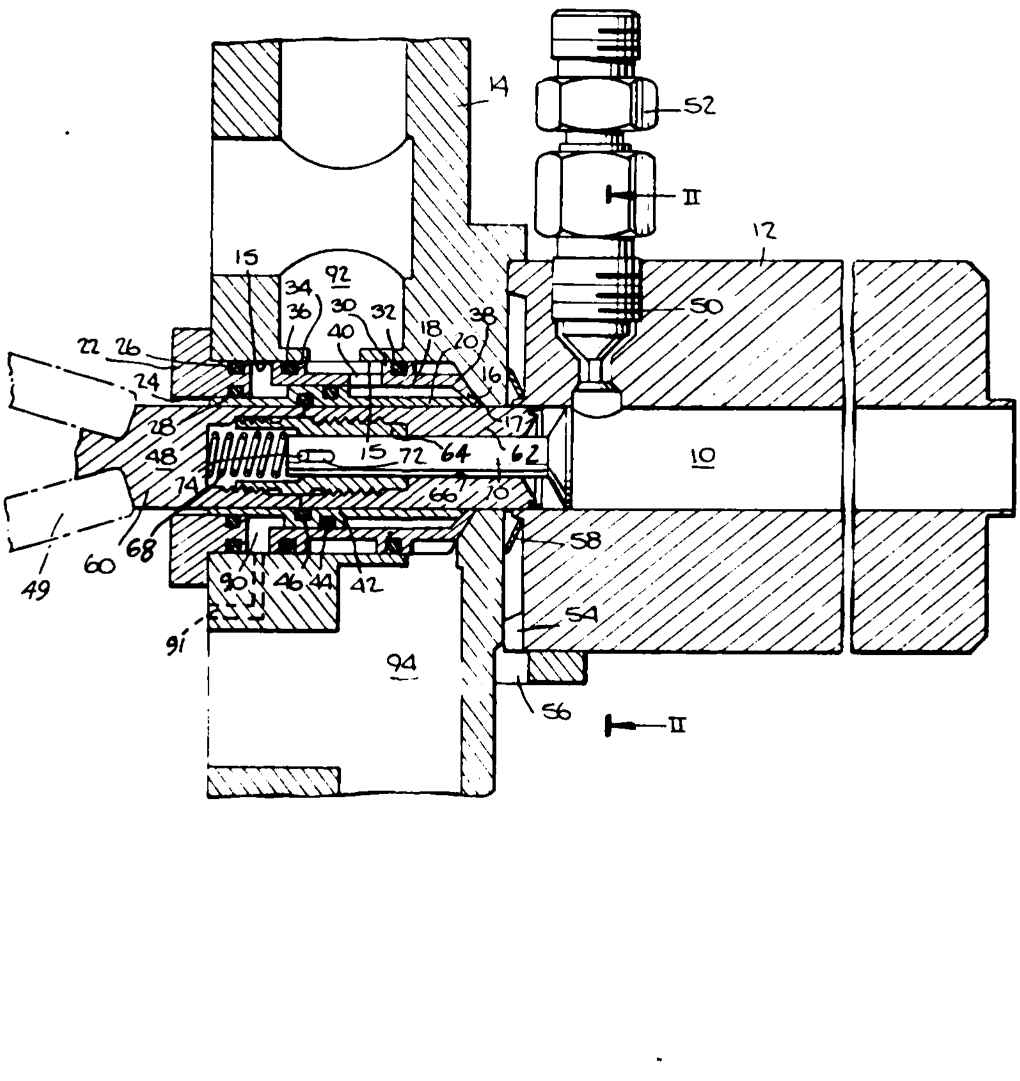
Primary Examiner—David H. Brown

Attorney, Agent, or Firm—Bailin L. Kuch

[57] **ABSTRACT**

A liquid investment seal is provided for the firing chamber of a gun, which seal is renewed at the commencement of each firing.

15 Claims, 9 Drawing Figures



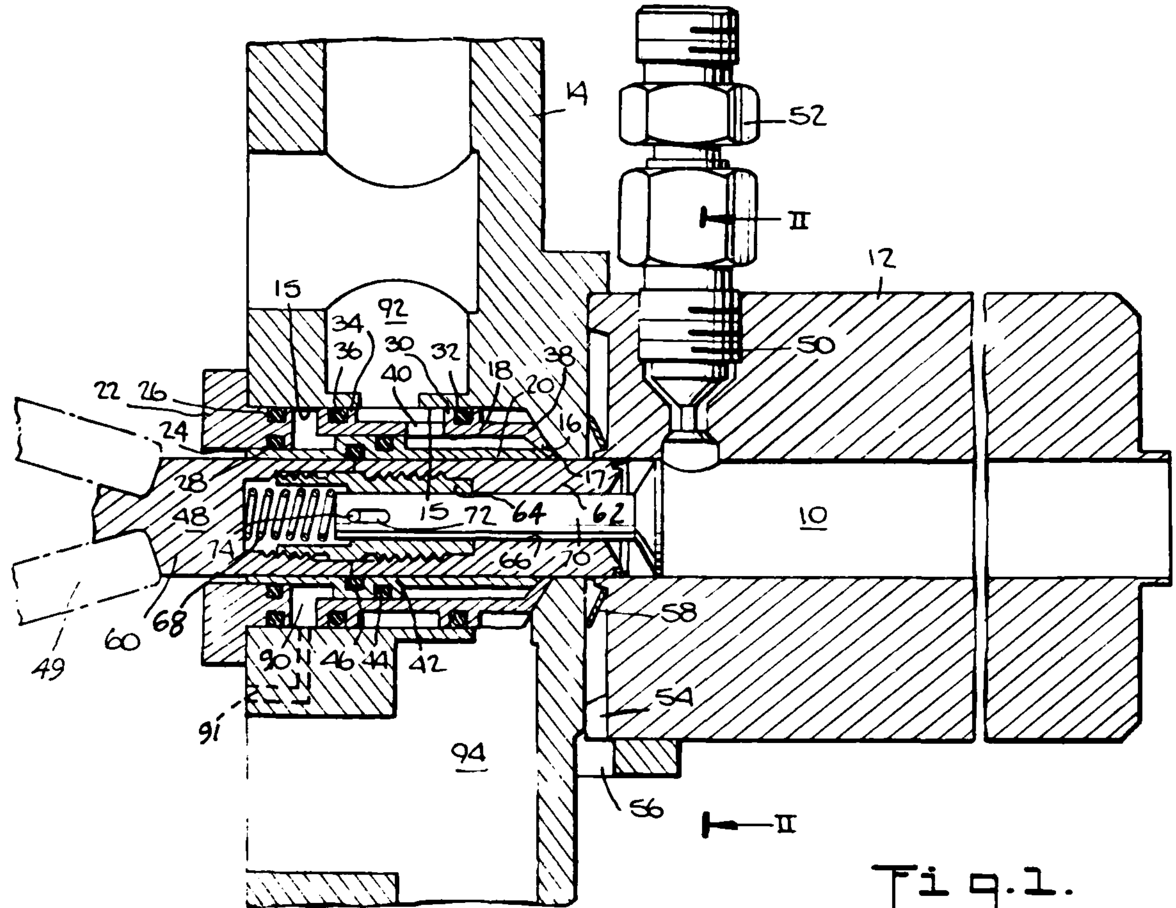

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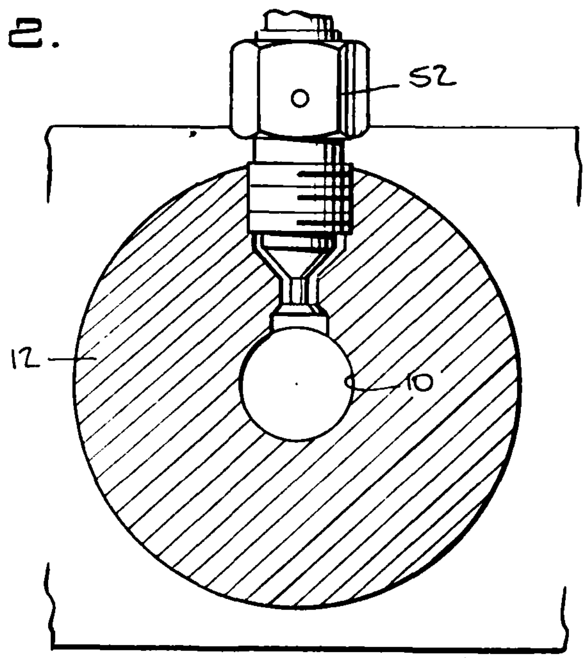
Fig.1.

Fig.2.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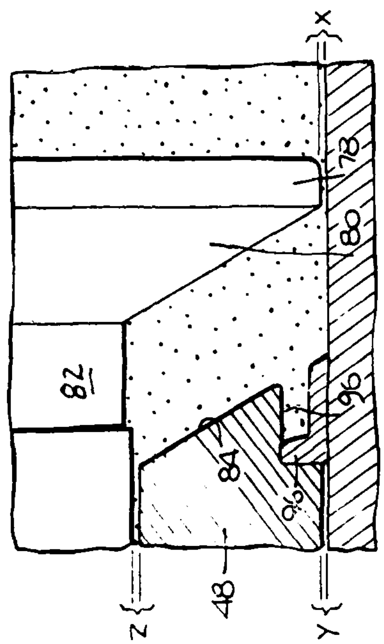

Fig.4.

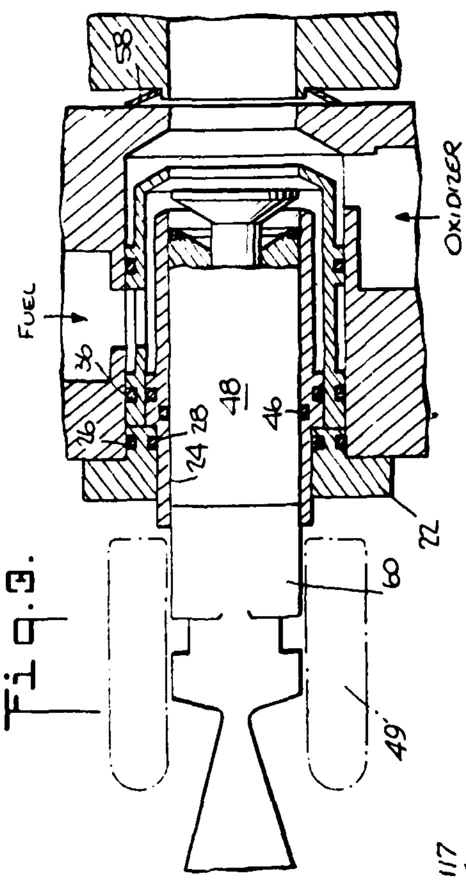

Fig.3.

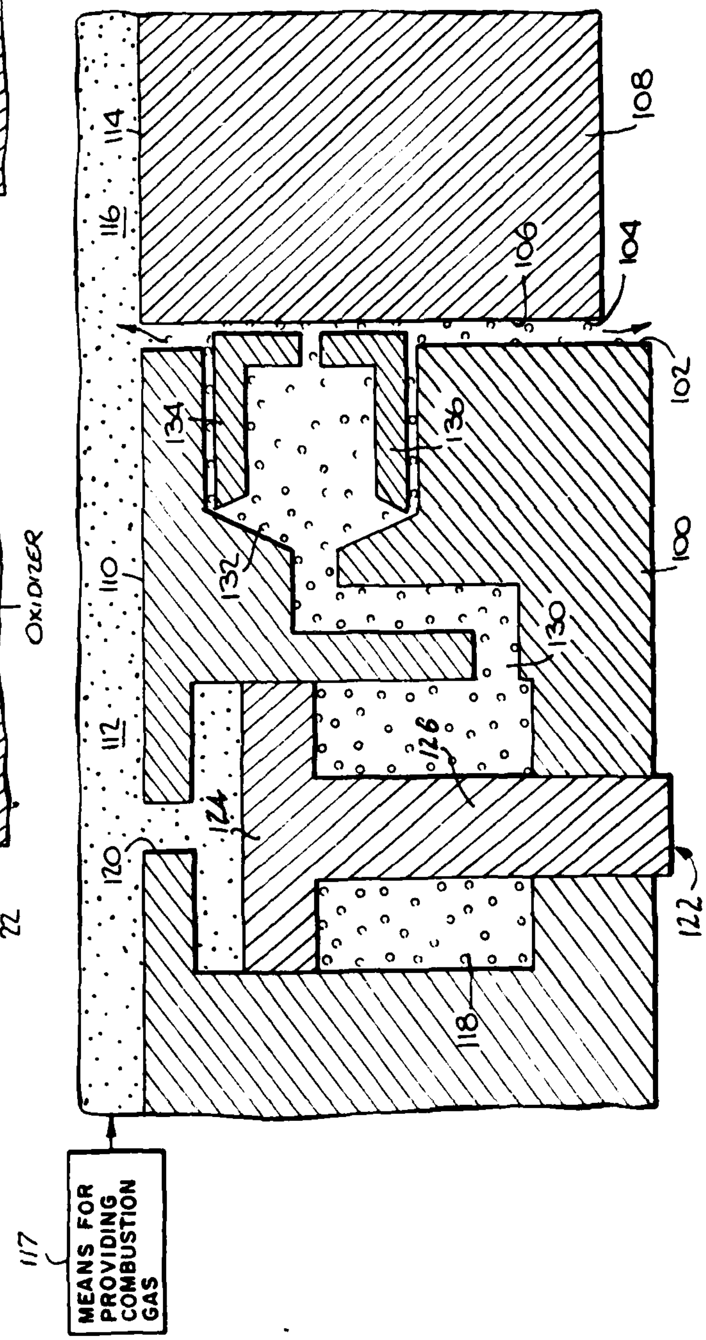

Fig.5.

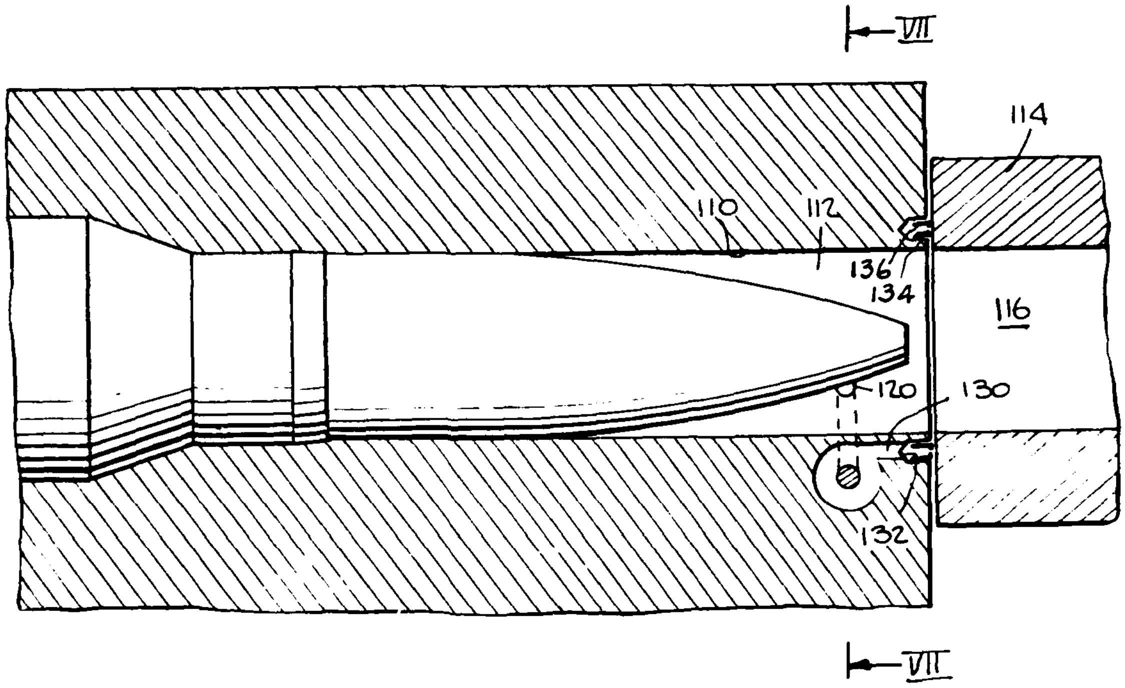
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Fig.6.

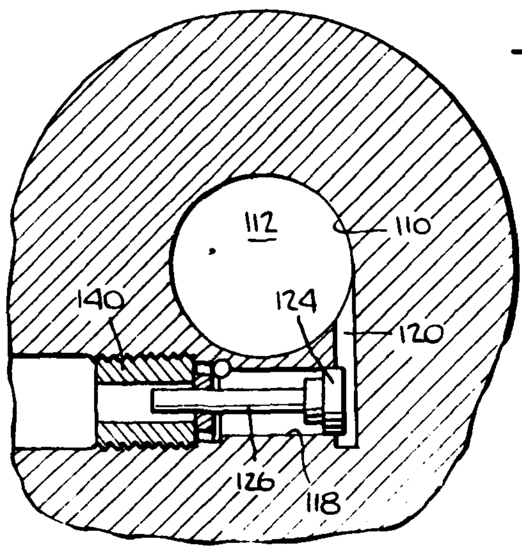
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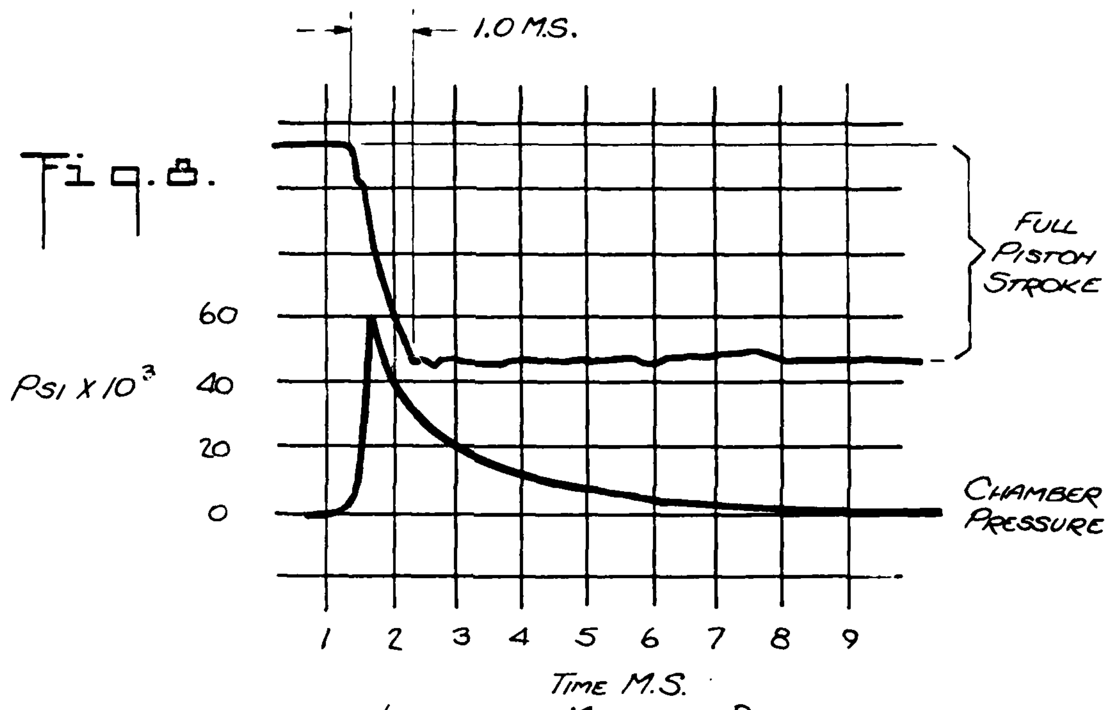
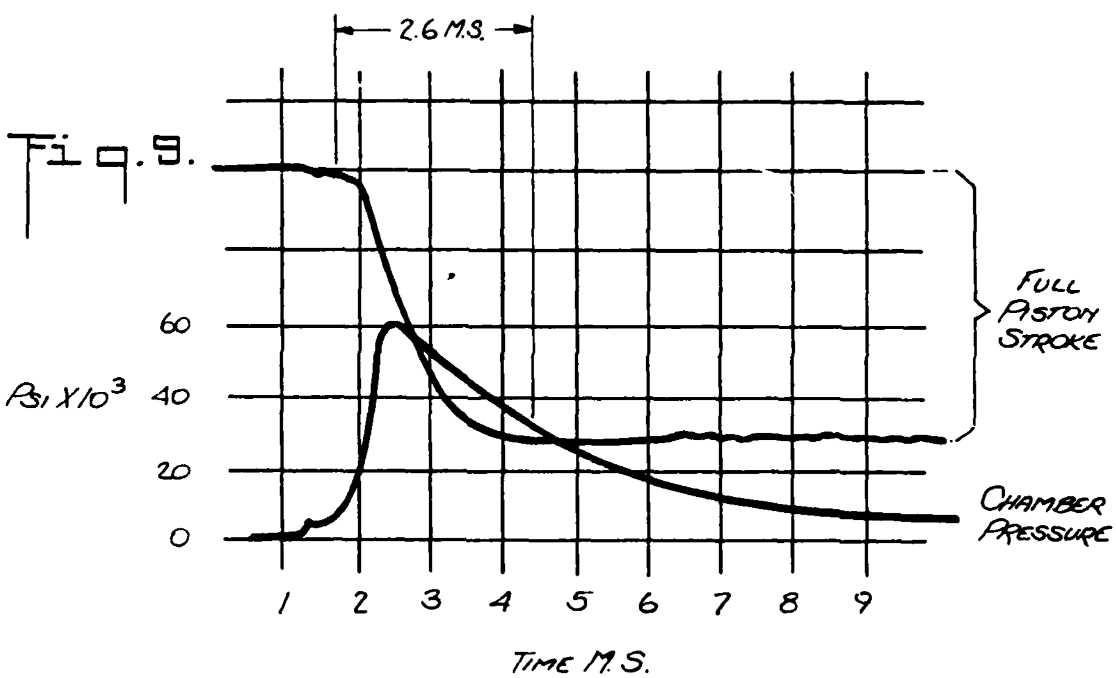
Fig.7.

Fig. 8.



INVESTMENT MATERIAL - DECALIN

Fig. 9.



INVESTMENT MATERIAL - GREASE

UNITED STATES PATENT OFFICE

CERTIFICATE OF CORRECTION

Patent No. 4,050,352 Dated Sept. 27, 1977

Inventor(s) Douglas Pray Tassie

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

Column 1, line 28 change "the" to --this--.
Column 2, line 46 change "cahmber" to --chamber--.
Column 5, line 40 change "ith" to --with--.

Signed and Sealed this

Fourteenth **Day of** *February 1978*

[SEAL]

Attest:

RUTH C. MASON
Attesting Officer

LUTRELLE F. PARKER
Acting Commissioner of Patents and Trademarks

RENEWABLE LIQUID INVESTMENT SEAL

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates to a liquid seal for combustion apparatus, especially adapted for use in liquid propellant, or caseless, or revolver type guns.

2. Prior Art

Annular seals are well known, and are shown, for example, in Hasek, U.S. Pat. No. 2,117,885; Asbury, U.S. Pat. No. 1,376,130; Gerdom, U.S. Pat. No. 539,733; Thierry, U.S. Pat. No. 3,006,254; Wankel, Germany DAS 1,096,697; and Ashley, U.S. Pat. No. 3,783,737. Each of these seals functions by stressing a ring into abutment with a bore to provide a close surface continuum, and is more or less effective for a limited number of firings.

SUMMARY OF THE INVENTION

Liquid propellant guns, other guns firing caseless ammunition, and revolver type guns must be provided with seals to prevent the escape of gas from the firing chamber during a repeated number of firings.

An object of this invention is to provide a seal for such guns which is effective during a repeated number of firings.

A feature of the invention is the provision of a liquid investment seal for the firing chamber of a gun which is renewed at the commencement of each firing.

BRIEF DESCRIPTION OF THE DRAWING

FIG. 1 is a longitudinal cross-section of a firing chamber for a liquid propellant gun, of the type shown, for example, by Tassie in U.S. Pat. No. 3,763,739, issued Oct. 9, 1973, showing a bolt incorporating this invention in its closed and locked disposition;

FIG. 2 is a transverse cross-section of the chamber of FIG. 1, taken along the plane II—II;

FIG. 3 is a detail view, in longitudinal cross-section, of the chamber of FIG. 1, showing the bolt in its unlocked and propellant filling disposition;

FIG. 4 is an enlarged detail view, in longitudinal cross-section, of the bolt and the chamber of FIG. 1, showing the generation of the liquid investment seal;

FIG. 5 is a schematic of a portion of a revolver having a firing chamber and a portion of a gun barrel, incorporating this invention;

FIG. 6 is a longitudinal cross-section of portions of a firing chamber and a gun barrel incorporating the mechanism of FIG. 5;

FIG. 7 is a transverse cross-section of the mechanism of FIG. 5 taken along the plane VII—VII;

FIG. 8 is a chart showing chamber pressure and seal-piston stroke against time using "decalin" as an investment material; and,

FIG. 9 is a chart showing chamber pressure and seal-piston stroke against time using grease as an investment material.

DESCRIPTION OF THE FIRST EMBODIMENT OF THE INVENTION

In guns firing conventional cased ammunition, the interface between the combustion or firing chamber and the gun bolt is sealed by the cartridge case. A new case is provided for each firing. In many prior art guns utilizing liquid propellant to fire a projectile without a cartridge case, the interface between the chamber and the

bolt is closed by a seal ring which is carried by the bolt. In most such guns, the seal ring is stressed by the combustion gas. There is a small initial leakage which causes heating and erosion of the seal ring, and often allows foreign particles to enter the gap and to interfere with the seating of the seal ring. In U.S. Pat. No. 3,783,737, which uses a pre-stressed ring seal, this problem is obviated; however, the metal-to-metal contact does eventually result in frictional wear, galling and fatigue.

To overcome all of these disadvantages this invention provides a liquid which is used to fill or to invest the joint or gap between the bolt and the combustion chamber at a pressure which is higher than the pressure of the combustion gas in the chamber, so that the investment liquid will flow into the chamber, rather than the combustion gas flowing into the joint. Flow control rings may be used to limit the rate of flow of the investment liquid to minimize the loss of the investment liquid.

FIG. 1 shows a combustion chamber **10** in a gun barrel **12** which is fixed to a barrel extension **14**, having a longitudinal bore or antechamber **15** having a conical transition portion **16** and a reduced diameter portion **17**. Two concentric sleeves **18** and **20** are disposed in the bore **15** which is capped by an L-ring **22** which is fixed to the extension **14** and extends within the bore **15**. The L-ring **22** has a longitudinal bore **24**, and an outer ring seal **26** and an inner ring seal **28**. The outer sleeve **18** has a forward annular rib **30** with an outer ring seal **32** and an aft annular rib **34** with an outer ring seal **36**, a forwardmost, inwardly projecting nose cone section **38**, and a plurality of radially extending bores **40** located between the ribs. The inner sleeve **20** has an intermediate annular rib **42** having an outer ring seal **44** and an inner ring seal **46**, and its aft end extends within the bore **24** against the ring seal **28**.

The gun bolt **48**, which may be locked to the barrel extension by conventional means, such as wing locks **49**, is disposed within the bore **24**, and within the inner sleeve **20**, against the ring seal **46**, and is reciprocatable into the aft portion of the combustion chamber **10**. A transverse bore **50** extends through the gun barrel **12** into the aft portion of the combustion chamber, and a spark plug **52** is fixed therein.

An annular recess **54** may be provided in the interface between the gun barrel **12** and the extension **14** about the cahmber **10** with a drain passageway **56** and an annular relief valve **58**.

The gun bolt **48** comprises a bolt aft body **60**, a bolt forward body **62**, and a tubular coupler **64** which fixes together the bodies **60** and **62**. The composite body has a blind longitudinal bore **66** in which are disposed a helical compression spring **68** and a piston **70**. The aft portion of the piston has a longitudinally extended, diametrical slot **72** in which is disposed a cross-pin **74** whose ends extend into a diametrical bore in the bolt body. The cross-pin thus captures the piston within the bore **66** while permitting limited reciprocation therein. The piston captures the spring **68** within the bore, while the spring biases the piston forwardly. The piston has a head which at its forwardmost end is disk-shaped as at **78** with a conical transition portion **80** leading to the stem **82**. The forward portion of the bore **66** is enlarged in a cone-shape, as at **84**, to mate with conical portion **80** of the piston head.

The longitudinal length of the sleeve **18**, from its forwardmost portion **38** to its aftmost portion **34** is shorter than the longitudinal length of the bore **15** from its forwardmost conical surface **16** to its aftmost trans-

verse surface provided by the ring **22**. Thus the sleeve **18** is free to slide to and between a forwardmost position shown in FIG. **1** and an aftmost position shown in FIG. **3**. Similarly, the longitudinal length of the sleeve **20** between it forwardmost end and the annular rib **42** is shorter than the open length of the bore **15**. When both sleeves are in their forwardmost positions a void **90** is defined in which is received a quantity of gas under pressure, supplied from a source, not shown, via a conduit **91** assembly. This gas serves as a gas spring, biasing the sleeves towards their forwardmost positions.

The barrel extension **14** also has a radial bore **92** which opens into the bore **15** between the ribs **30** and **34** of the sleeve **18** when the sleeve **18** is in either its fore or aft position. The extension also has a radial bore **94** which opens into the bore **15** forward of the annular rib **30** when the sleeve **18** is in either its fore or aft position. In a liquid propellant gun of the type taught in U.S. Pat. No. 3,763,739, a measured quantity of liquid fuel is pumped through the bore **92** while a measured quantity of liquid oxidizer is pumped through the bore **94**. These liquids force the sleeves aft, against the bias of the gas spring, so that fuel passes through the radial bores **40** in the sleeve **18**, then forwardly between the sleeves, then around the head of the piston and into the combustion chamber; while oxidizer passes around the conical portion of the sleeve **18** into the combustion chamber. When the supply of fuel and oxidizer under pressure ceases, the gas spring biases the sleeves forwardly, as shown in FIG. **1**, to provide a seal between the sleeves **20** and **18** and the barrel extension, forward of the supply bores **92** and **94**. The annular flows of fuel and oxidizer guided by the sleeves **18** and **30** intermix to fill the combustion chamber with a relatively homogeneous mixture. A quantity of this liquid mixture is trapped in the annular void between the aft conical surface of the head of the piston and the mating conical surface of the bolt body. As shown in FIG. **4**, a leakage interface Z exists between the bolt body and the piston stem, a leakage interface Y exists between the bolt body and the barrel, and a leakage interface X exists between the piston head and the barrel. To permit a more generous clearance between the bolt body and the chamber wall of the barrel, an L-ring seal **96** may be disposed in an annular notch **98** cut into the forward-outer corner of the bolt body. This ring differs from a conventional seal in that no preload against the chamber wall is necessary.

When ignition is provided by the spark plug, the mixture of fuel and oxidizer forward of the piston head adjacent the spark plug burns and generates combustion gas under relatively high pressure. This gas pressure is communicated to the piston head, biasing it aft against the return spring. The liquid trapped or invested behind the piston head is under a relatively higher pressure than the combustion gas, which is equal to the piston head transverse area divided by the difference of the piston head transverse area and the piston stem cross-sectional area, all multiplied by the combustion gas pressure. The invested liquid flows out of the interfaces X, Y, and Z at this relatively high pressure. This forward flow at X, being at a higher pressure than the liquid or gas pressure in the chamber forward of the piston head, precludes any flow aftward of combustion gas at X. The use of the L-ring seal **96** effectively precludes any significant flow of investment liquid at Y, which would otherwise ultimately pass to the atmosphere.

DESCRIPTION OF THE SECOND EMBODIMENT OF THE INVENTION

The invention may also be utilized to seal a revolver to a gun barrel. An exemplary revolver gun is shown in the Final Report, 19 Nov. 1953-31 Jan. 1956, under contract DA-36-034-ORD-1504RD, Project TS1-47-8, page 31, FIG. **16**. As is schematically shown in FIG. **5**, a revolver **100** has a transverse forward face **102** which is spaced by a leakage interface **104** from a transverse aft face **106** of a gun barrel **108**. The inner wall **110** of a chamber **112** of the revolver is aligned with the inner wall **114** of the bore **116** of the gun barrel. Conventional means **117** provide combustion gas to the chamber **112**, or the system shown in FIG. **1** may be utilized. A cylinder **118** is provided in the wall of the revolver and has a combustion gas inlet port **120**. A piston **122** having a head **124** and a stem **126** is disposed in the cylinder. The cylinder also has an outlet port **130** which communicates with an annular recess **132** cut into the surface **102** and coaxial with the chamber **112**. A pair of flow control L-shaped rings **134** and **136** may be disposed in the recess. The cylinder below the piston head is filled with a suitable investment liquid such as grease which can be pumped by the piston head through the recess and into the leakage interface **104**. As before, the investment liquid will be pumped into the leakage interface at a pressure which is higher than the pressure of the combustion gas, and which is equal to the piston head transverse area divided by the difference of the piston head transverse area and the piston stem cross-sectional area, all multiplied by the combustion gas pressure.

As shown in FIGS. **6** and **7**, the piston and the investment liquid may be retained in the cylinder by means of a plug **140**. Suitable means for automatically charging the cylinder with a supply of grease between bursts of firing may be provided by an auxiliary pumping system, not shown.

The flow control rings are forced into the leakage interface **104**. The rate of flow permitted by the rings is determined by surface conditions. Flow towards the atmosphere should be held to a minimum, while flow towards the chamber/bore should be more generous to fill the interface joint to preclude combustion gas from entering. Investment liquid, such as Molybdenum disulphide, should be selected to meet the high temperature and high pressure conditions provided by the combustion gas.

FIG. **8** shows piston stroke and chamber pressure versus time in a mechanism shown in FIG. **1** utilizing decalin as the investment liquid.

FIG. **9** is similar to FIG. **8**, but utilizing a MIL-G-3278A grease.

What is claimed:

1. An engine comprising:
   - a combustion chamber;
   - a first means cyclically reciprocatable between a first station for closing one end of said combustion chamber and a second station for opening said one end of said combustion chamber;
   - said first means, when closing said combustion chamber, having a common interface therewith;
   - second means for providing combustion gas at a variable first pressure in said chamber;
   - third means for providing a liquid into said common interface at a variable second pressure which is always greater than said first pressure, whereby

such liquid seals said common interface and a portion thereof flows into said combustion chamber.

2. An engine according to claim 1, wherein:
said third means includes
a pump having
a supply of such liquid having an outlet communicating with said common interface, and
a piston having a first face of a first cross-sectional area communicating with said combustion chamber, and a second face of a second cross-sectional area, which is smaller than said first area, communicating with said supply of such liquid.

3. An engine according to claim 1 wherein:
said engine is a gun;
said combustion chamber is part of a gun bore; and
said first means is a breech block.

4. An engine according to claim 1 wherein:
said engine is a gun;
said combustion chamber is part of a gun bore; and said first means is a gun bolt.

5. An engine comprising:
a combustion chamber having an outlet port;
a conduit for juxtaposition with said outlet port;
said conduit, when juxtaposed with said outlet port, having a common interface therewith;
first means for providing combustion gas at a variable first pressure in said chamber;
second means fr . providing a liquid into said common interface at a variable second pressure which is always greater than said first pressure, whereby said liquid seals said common interface and a portion thereof flows into said combustion chamber.

6. An engine according to claim 5, wherein:
said second means includes
a pump having
a supply of such liquid having an outlet communicating
ith said common interface, and
a piston having a first face of a first cross-sectional area communicating with said combustion chamber, and a second face of a second cross-sectional area, which is smaller than said first area, communicating with said supply of such liquid.

7. An engine according to claim 5 wherein:
said engine is a gun;
said combustion chamber is part of a revolver; and
said conduit is a gun bore.

8. A gun comprising:
a gun barrel having a combustion chamber;
a gun bolt for closing one end of said chamber;
said bolt including:
a bolt body having a longitudinal bore therein,
a piston having a head disposed forward of said body and a stem journaled for reciprocation in said bolt body bore,
said piston head having a forward face of a first cross-sectional area proximal to and in communication with said chamber, and an aft face of a second cross-sectional area, which is less than said first cross-sectional area, and which is spaced from said bolt body to mutually define a void;
means for trapping liquid in said void; and
having a mode of operation such that force applied to said piston head forward face at a first pressure is communicated to liquid in said void by said piston head aft face at a second pressure which is greater than said first pressure.

9. A gun according to claim 8 wherein:
said gun bolt is adapted to be locked to said gun barrel, in which disposition said piston head and the forward portion of said bolt body enter the aft portion of said chamber, said piston head defining a first transverse clearance gap with respect to the adjacent wall of said chamber and said bolt body forward portion defining a second transverse clearance gap with respect to said adjacent wall of said chamber which is less than said first gap.

10. A gun according to claim 8 further including:
spring means coupled to and between said bolt body and said piston to urge an increase in the longitudinal size of said void, and wherein
force applied to said piston head forward face urges a decrease in the longitudinal size of said void.

11. A gun for firing liquid propellant comprising:
a gun barrel having a bore, a combustion chamber and an antechamber in serial, longitudinal alignment,
an inlet port opening into said antechamber,
a bolt journaled for longitudinal reciprocation and having at least two longitudinal dispositions,
a first disposition, whereat said bolt is aft of said inlet port, and permits liquid flow from said inlet port to said combustion chamber, and
a second disposition, forward of said first disposition, whereat said bolt obturates said combustion chamber and precludes liquid flow between said inlet port and said combustion chamber;
said bolt including:
a bolt body having a longitudinal bore therein,
a piston having a head disposed forward of said body and a stem journaled for limited reciprocation in said bolt body bore,
said piston head having a forward face of a first cross-sectional area, and an aft face of a second cross-sectional area, which is less than said first cross-sectional area,
means urging said piston forward of said bolt body, whereat said aft face of said piston head is spaced forward of said bolt body to mutually define a void;
said void adapted to receive liquid from said inlet port when said bolt is in its first disposition, and to trap liquid, in conjunction with the wall of said combustion chamber, when said bolt is in its second disposition;
said bolt having a mode of operation such that force applied to said piston head forward face by combustion gas at a first pressure in said combustion chamber is communicated to liquid trapped in said void by said piston head aft face at a second pressure which is greater than said first pressure.

12. A gun according to claim 11 further including:
a sleeve journaled for reciprocation on said bolt body and having a first disposition for permitting the flow of liquid from said inlet port towards said combustion chamber, and a second disposition for precluding the flow of liquid from said inlet port towards said combustion chamber;
spring means urging said sleeve to said second disposition; and
having a mode of operation such that the flow of liquid under pressure from said inlet port serves to displace said sleeve to said first disposition.

13. A gun according to claim 11 wherein:

said bolt body has a forward transverse face adapted to nest with said piston head aft face.

14. A gun according to claim **13** wherein:

said bolt body forward portion has a diameter which is greater than the diameter of said piston head.

15. A gun according to claim **14** wherein said diameter of said bolt body forward portion is provided by an L-ring seal which communicates with said void.

* * * * *

United States Patent [19]

Ashley

[11] 4,051,762

[45] Oct. 4, 1977

[54] LIQUID PROPELLANT WEAPON SYSTEM

[75] Inventor: Eugene Ashley, Burlington, Vt.

[73] Assignee: General Electric Company, Burlington, Vt.

[21] Appl. No.: 728,355

[22] Filed: Sept. 30, 1976

Related U.S. Application Data

[62] Division of Ser. No. 575,283, May 7, 1975, Pat. No. 4,011,817, and Ser. No. 707,144, July 20, 1976, which is a division of Ser. No. 469,507, May 13, 1974, abandoned.

[51] Int. Cl.² F41F 1/04
[52] U.S. Cl. 89/7; 102/38
[58] Field of Search .... 102/38, 40, 43 R, 38 R; 89/7

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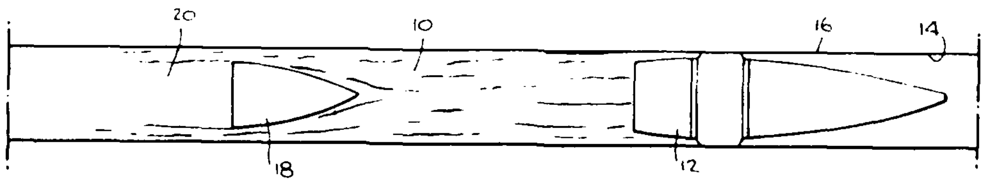
Primary Examiner—David H. Brown
Attorney, Agent, or Firm—Bailin L. Kuch

[57] **ABSTRACT**

A gun and ammunition system is provided which utilizes the difference in density between the combustion gases and the charge of liquid propellant as the source of energy for the injection of propellant into the combustion chamber.

5 Claims, 18 Drawing Figures



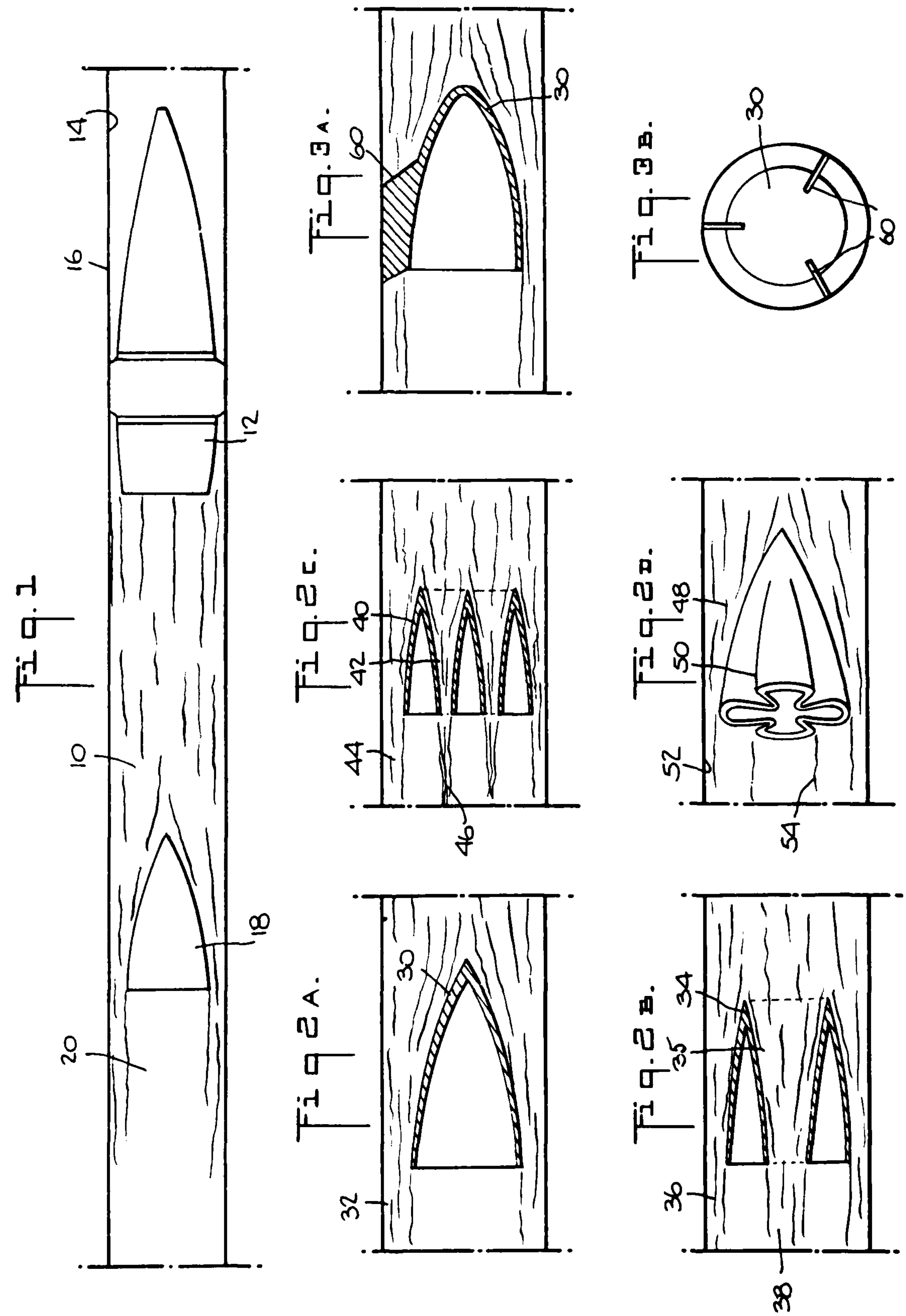


Fig. 1
14
16
12
10
18
20
Fig. 3A.
60
30
Fig. 3B.
30
60
Fig. 2C.
40
42
44
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Fig. 2D.
48
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52
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Fig. 2A.
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Fig. 2B.
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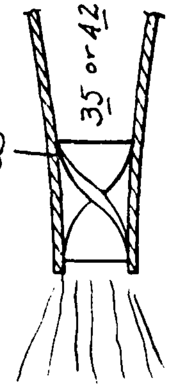


Fig. 4C.

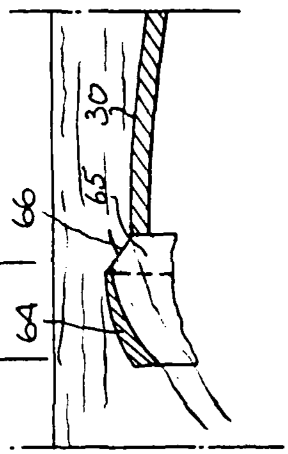


Fig. 4B.

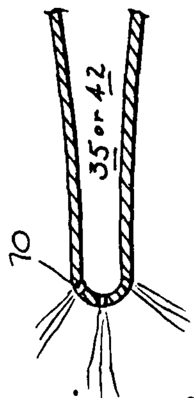


Fig. 4D.

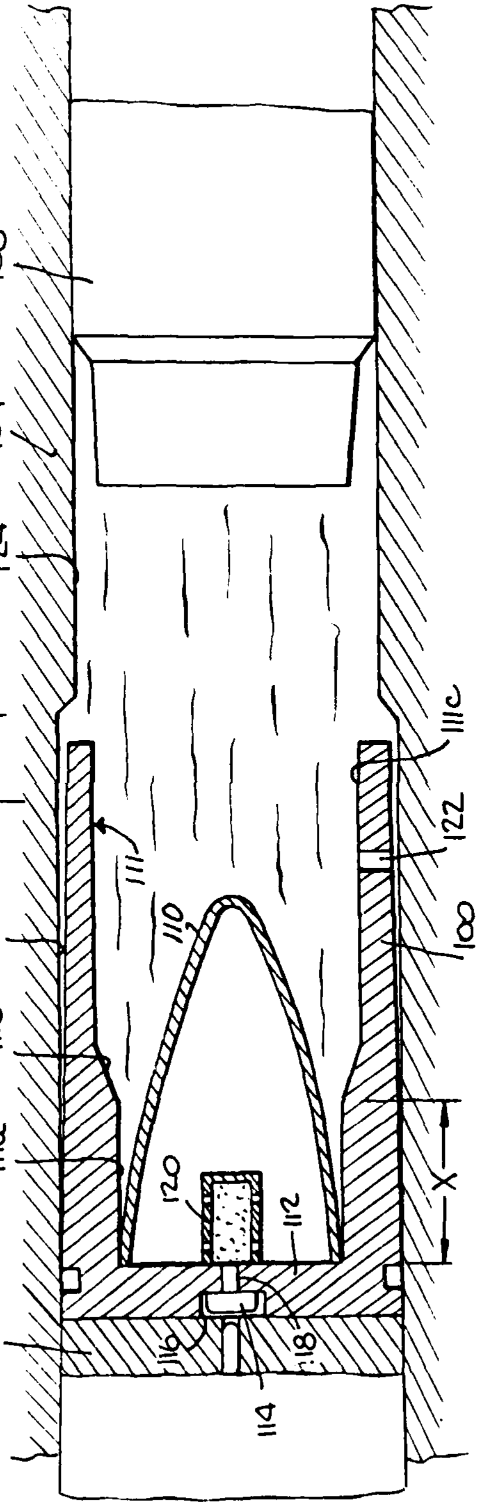


Fig. 6.

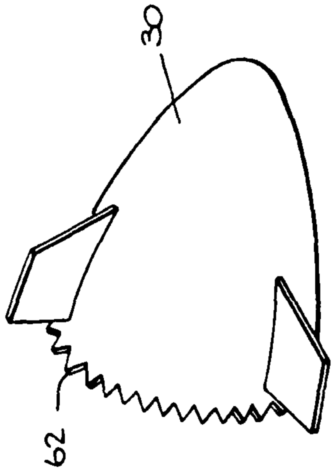


Fig. 4A.

Fig. 5A.

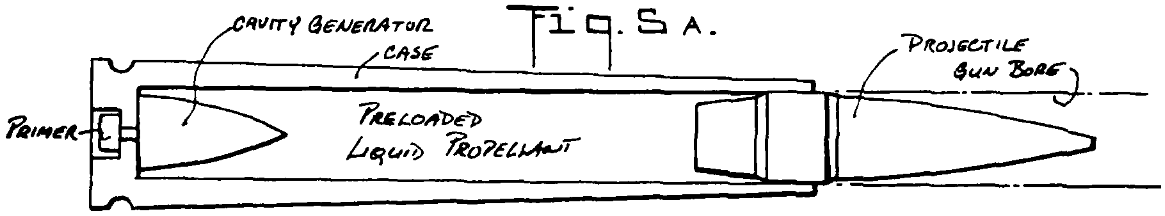


Fig. 5B.

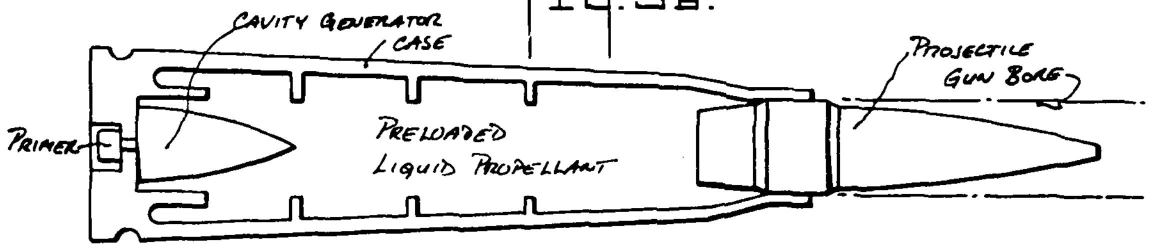


Fig. 5C.

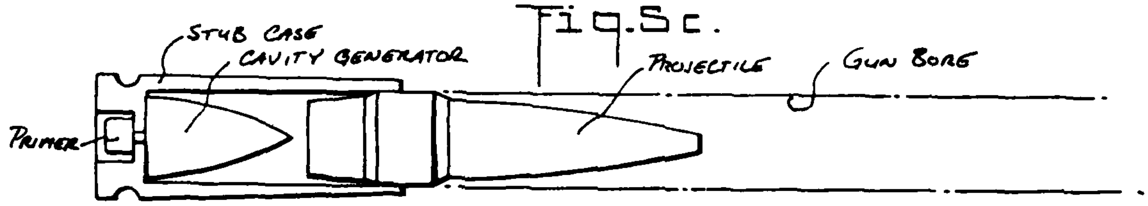


Fig. 5D.

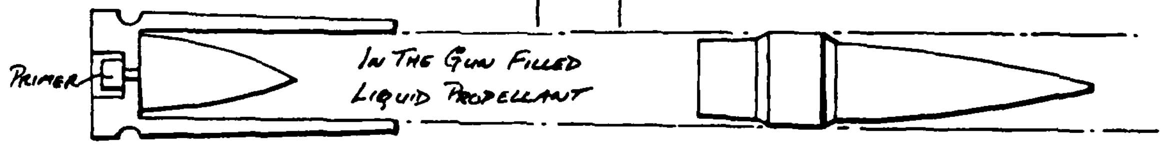


Fig. 5E.

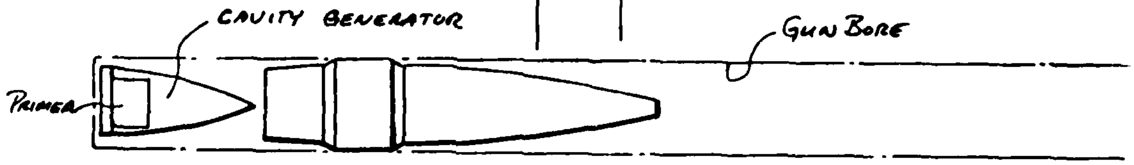
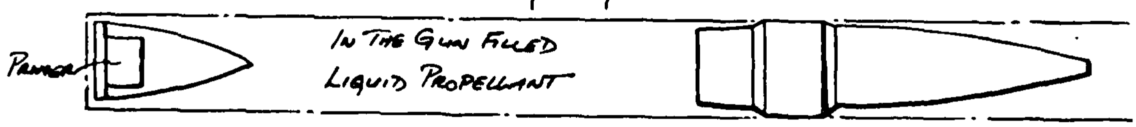


Fig. 5F.



UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 4,051,762 Dated October 4, 1977

Inventor(s) Eugene Ashley

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

Column 5, line 3 change "γ_{CG}" to --Γ_{CG}--; line 4 change "γ_L" to --Γ_L--; line 16 change "a" to --in--.

Signed and Sealed this

Twenty-first **Day of** *February 1978*

[SEAL]

Attest:

RUTH C. MASON
Attesting Officer

LUTRELLE F. PARKER
Acting Commissioner of Patents and Trademarks

LIQUID PROPELLANT WEAPON SYSTEM

RELATED CASE

This application is a division of Ser. No. 575,283, filed May 7, 1975, now U.S. Pat. No. 4,011,817. This application is also a division of Ser. No. 707,144, filed July 20, 1976, which was a division of Ser. No. 469,507, filed May 13, 1974, now abandoned.

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates to weapons systems employing a liquid propellant, and particularly to such systems wherein the propellant is continuously pumped into the combustion chamber aft of the projectile as the projectile advances along the firing bore.

2. Prior Art

In my earlier patent application, Ser. No. 469,507, filed May 13, 1974, now abandoned, and continued as Ser. No. 707,143 and Ser. No. 707,144, both filed July 20, 1976, I disclosed a gun and ammunition system utilizing a round of ammunition carrying a relatively narrow diameter and relatively high mass projectile in a relatively wide and relatively low mass sabot which is initially accelerated by a primary propellant charge in the combustion chamber aft of the projectile and which is passed during a relatively extended period of time to the combustion chamber. Additional prior art is cited and discussed in that application which is hereby incorporated by reference.

SUMMARY OF THE INVENTION

An object of this invention is to provide a gun and ammunition system utilizing a liquid propellant traveling charge which is simpler than the area differential system disclosed in Ser. No. 469,507 supra.

A feature of this invention is the provision of a gun and ammunition system which utilizes the difference in density between the combustion gases and the charge of liquid propellant as the source of energy for the injection of propellant into the combustion chamber.

During the combustion of the propellant, an extremely steep inertial gradient exists between the face of the gun bolt and the projectile; and the lighter combustion gas propagates forwardly into the liquid charge of propellant. An injector device is provided which has a lower average density than the density of the liquid charge and which utilizes this difference in density to control the entrance of liquid propellant in the combustion zone or chamber. The injector device also defines and controls the interface between the liquid propellant and the combustion gas and provides a true traveling charge effect.

BRIEF DESCRIPTION OF THE DRAWING

These and other objects, features, and advantages of this invention will be apparent from the following specification thereof taken in conjunction with the accompanying drawing in which:

FIG. **1** is a schematic view of a gun and ammunition system embodying this invention;

FIGS. **2A**, **2B**, **2C**, and **2D** are schematic views of various species of cavity generators embodying this invention;

FIGS. **3A** and **3B** are schematic views of a fin-stabilized cavity generator embodying this invention;

FIGS. **4A**, **4B**, **4C**, and **4D** are schematic detail views of additional species of cavity generators embodying this invention;

FIGS. **5A** and **5B** are schematic longitudinal cross-section views of two species of a cased, pre-loaded liquid propellant round of ammunition embodying this invention;

FIGS. **5C** and **5D** are schematic longitudinal cross-section views of a stub-cased, in-the-gun-filled round of ammunition before and after loading with liquid propellant, respectively, and embodying this invention;

FIGS. **5E** and **5F** are schematic longitudinal cross-section views of a caseless, in-the-gun-filled round of ammunition before and after loading with liquid propellant, respectively, and embodying this invention; and

FIG. **6** is a detail view in longitudinal cross-section of the round of FIG. **5D**.

DESCRIPTION OF THE EMBODIMENTS

Taylor cavity formation and subsequent Helmholtz mixing are considered fundamental mechanisms in bulk-loaded liquid propellant guns. Behavior of the liquid gas interface, and hence of combustion processes, are attributed to these phenomena. The dynamics of two-phase flow under accelerations as extreme as those in guns support this supposition, and evidence exists to confirm it. Though chamber pressures are higher than critical, and transition between phases takes place differently than at lower pressure levels, large density differences must exist between burned and unburned charges. The less dense regions of combustion products undoubtedly migrate through the denser unburned propellant. Much turbulence and liquid break-up certainly occurs.

FIG. **1** shows a liquid propellant traveling charge **10** behind a projectile **12** in a bore **14** in a gun barrel **16**. Acceleration is taking place toward the right. Behind the liquid charge is shown a new component: a cavity generator **18**. This is here shown as an ogive having a circular arc body of revolution. Behind the cavity generator **18** is the combustion zone **20** containing the hot gases which constitute the products of combustion. The cavity generator substantially separates the main body of the liquid charge from the combustion gases.

The design of the cavity generator **18** gives it another more significant function. It is constructed so that its density is less than that of the liquid charge **10** surrounding it. In the high inertial gradient associated with acceleration in the gun barrel, the lighter cavity generator will tend to penetrate the liquid charge. This is analogous to the penetration of gas in the Taylor cavity theory as applied to guns. As the cavity generator penetrates, it will displace liquid which necessarily flows rearward of the generator in a relative sense. The cavity generator thus acts as an injector system, controlling the rate at which liquid charge enters the combustion zone. As it penetrates into the liquid charge, the cavity generator literally shapes and controls a quasi-Taylor cavity.

FIG. **1** shows the cavity generator as a solid displacement body of appropriate density to aid in visualization. However, a solid body of revolution is not necessarily the most practical arrangement for actual application. It occupies volume in the chamber before firing, and it must be expelled as debris after the projectile leaves the muzzle. It is advantageous to reduce its bulk.

One way of reducing the bulk of the cavity generator is to make the generator hollow. Instead of a solid body, it becomes a thin shell, open at the rear and filled with

combustion gas. The products of combustion will have variable density as pressure changes, but the average density of the products of combustion and the generator will always be less than that of the unburned liquid charge.

In this approach, the lightest, thinnest design is utilized. The cavity generator acts more as a gas-filled balloon or membrane than as a solid displacement body.

Other species have utility. Multiple shells can be used in place of a single one, and possibilities arise for varying the character of propellant flow into the combustion zone.

FIGS. **2A** through **2D** show four different examples of cavity generator design, each of which will produce its own pattern of propellant flow. FIG. **2A** shows a single shell **30** construction, providing a conventional Taylor cavity configuration with a single wall of fluid **32.** FIG. **2B** shows a single shell **34** having a central bore **35,** providing a single outer wall of fluid **36** and a central column of fluid **38.** FIG. **2C** shows a single shell **40** having an annular row of bores **42,** providing a single outer wall of fluid **44** and an annular row of columns of fluid **46.** FIG. **2D** shows a single shell **48** having an annular row of flutes **50** in the surface thereof, providing a single outer wall of fluid **52** with an annular row of ridges **54.**

One or more stabilizing fins **60** may be provided as shown in FIGS. **3A** and **3B** to maintain the generator on a longitudinal axial path while providing a thick outer wall of fluid.

Features incorporated into cavity generator design can further modify the character of the propellant/gas interface. FIGS. **4A** through **4D** illustrate a number of species. Each of these will affect the nature of the propellant surface exposed to combustion products, with resultant effect upon burning.

FIG. **4A** shows a series of serrations **62** provided in the trailing edge of the shell **30** and bent outwardly to act as flow spoilers. FIG. **4B** shows a series of tabs **64** spaced by apertures **65** and webs **66** from the trailing edge of the shell **30** and bent inwardly to deflect portions of flowing outer wall of liquid into the combustion chamber. FIG. **4C** shows a swirl generator **68** disposed in each bore **35** or **42.** FIG. **4D** shows a closure with a plurality of small orifices **70** disposed in each bore **35** or **42** for the injection of streams of propellant into the combustion chamber.

The cavity generator represents debris which must leave the muzzle of the gun behind the projectile. Unless it is made completely frangible or consumable, the cavity generator concept is not as well adapted to aircraft guns as to ground-based applications. The lowest possible weight is necessary, however, and the mass expelled must be minimal for most applications.

The cavity generator leaves the gun concurrently with the projectile and so has the advantage of being a one-shot component. It is most practical to combine the cavity generator with a priming system and to supply these components to the gun together with the projectile. Such an approach proves to be quite flexible in its applicability. FIGS. **5A** through **5F** illustrate three different arrangements. FIGS. **5A** and **5B** show a fully preloaded, cased configuration round, as employed in guns handling conventional ammunition. FIGS. **5C** and **5D** show a stub-case, dry-loaded round in-the-gun-filled configuration. FIGS. **5E** and **5F** show a caseless, generator and projectile individually loaded round, in-the-gun-filled configuration. For details of the loading and filling operations, reference should be had to my disclosure in U.S. Pat. Application Ser. No. 469,507, filed May 13, 1974.

It is necessary to initiate the inertial field which produces the Taylor cavity behind the injector quickly, before combustion progresses out into the charge ahead of the cavity generator **30.** FIG. **6** shows a stub case, dry loaded, in-the-gun-filled round of ammunition, similar to that shown in FIG. **5D.** The stub case **100** is locked into the chamber **102** of the barrel **104** by a bolt **106.** A projectile **108** closes the open end of the case. A cavity generator **110** is disposed within the bore **111** of the case against the base **112** thereof. The bore **111** has a portion of smallest diameter **111*a*** adjacent the base, a portion of enlarging diameter **111*b*,** and a portion of largest diameter **111*c*** adjacent the mouth of the case. The outside diameter of the base of the generator is made equal to the inside diameter of the bore portion **111*a*.** A primer **114** is fixed in a cup **116** in the base **112** and communicates through a flash bore **118** with a booster **120** which is fixed to the base within the case and within the generator **110.** Liquid propellant is charged into the case through a port **122** in the case from a valving system which is not shown. The charge of liquid propellant displaces the projectile forwardly into the bore **124** of the barrel **104.** The primer is fired to initiate the booster to generate hot gas for the ignition of the charge of liquid propellant. At first, the booster-generated gas is confined within the hollow shell of the generator **110.** The pressure of the booster-generated gas begins to accelerate the assembly of the generator, the charge of liquid propellant and the projectile, which assembly will travel a distance (X) before the hot booster-generated gas and the liquid propellant will meet. This distance (X) is predetermined by the longitudinal length of the bore portion **111*a*** in the case. The rate of initial intermixing of the hot gas and the propellant can be controlled by varying the taper of the diameter of the bore portion **111*b*.** The stabilizing fin **60** of FIG. **3A,** if required, may extend from the forward part of the generator to the bore portion **111*a*.**

A simplified analysis of the cavity generator system follows: Muzzle velocity and pressure-time relationships in the chamber are the parameters of most interest in assessing performance. Turning again to the basic arrangement illustrated in FIG. **1,** the key factor in controlling combustion is the rate at which propellant enters the combustion zone from around the periphery of the cavity generator. This, in turn, is a direct result of the rate at which the cavity generator penetrates the unburned charge, for it is this action which displaces fluid rearward into the combustion chamber. The first step, therefore, is to establish the velocity of the cavity generator relative to the liquid charge and projectile.

From equations for the cavity generator and the liquid charge, an expression has been developed for the velocity with which the cavity generator penetrates the charge, as a function of various parameters. The expression for penetration velocity is:

$$V_2 = \sqrt{\frac{2aV_{CG}\left(1 - \frac{\Gamma_{CG}}{\Gamma_L}\right)}{A_c\left(\frac{A_c^2}{(A_c - A_1)^2} - 1\right)}}$$

where

V_2 = penetration velocity
a = projectile acceleration
γ_{CG} = specific gravity of cavity generator
γ_L = specific gravity of liquid propellant
V_{CG} = volume of cavity generator
A_1 = cavity generator base area
A_c = bore area

Penetration velocity gives a measure of the flow rate of propellant into the combustion zone. This can be combined with equations for the energy balance within the gun chamber to calculate chamber pressure and projectile motion as functions of time.

What is claimed is:

1. A method of propelling a projectile from a bore of a gun comprising:
   providing a series in said bore of said gun a projectile, a charge of liquid propellant aft of said projectile, and a cavity generator aft of said projectile and said charge;
   providing a volume of combustion gas in said bore of said gun aft of said cavity generator to create a combustion cavity; and

   translating said generator forwardly into said charge of liquid propellant to enlarge said combustion cavity and to pass liquid propellant aftwardly into said cavity.

2. A method according to claim 1 further including:
   finely dividing the liquid propellant as it is passed into the combustion cavity.

3. A method according to claim 1 further including:
   passing the liquid propellant into said combustion cavity at a rate which is a function of the penetration velocity of the generator into the charge of liquid propellant.

4. A method according to claim 1 wherein:
   said cavity generator has a forward face and an aft face, the cross-sectional area of said forward face being equal to the cross-sectional area of said aft face.

5. A method according to claim 1 wherein:
   the average density of said cavity generator is less than the average density of said charge of liquid propellant.

* * * * *

United States Patent [19]

Ashley

[11] **4,063,486**

[45] **Dec. 20, 1977**

[54] **LIQUID PROPELLANT WEAPON SYSTEM**

[75] Inventor: **Eugene Ashley**, Burlington, Vt.

[73] Assignee: **General Electric Company**, Burlington, Vt.

[21] Appl. No.: **707,144**

[22] Filed: **July 20, 1976**

Related U.S. Application Data

[63] Continuation of Ser. No. 469,507, May 13, 1974, abandoned.

[51] **Int. Cl.**[2] **F41F 1/04**

[52] **U.S. Cl.** **89/7; 102/38**

[58] **Field of Search** 102/38, 40, 93; 89/7, 89/8

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Primary Examiner—David H. Brown

Attorney, Agent, or Firm—Bailin L. Kuch

[57] **ABSTRACT**

A gun and ammunition system utilizing a round of ammunition which contains a supply of liquid propellant and after ignition pumps this propellant into the combustion chamber of the gun.

39 Claims, 21 Drawing Figures

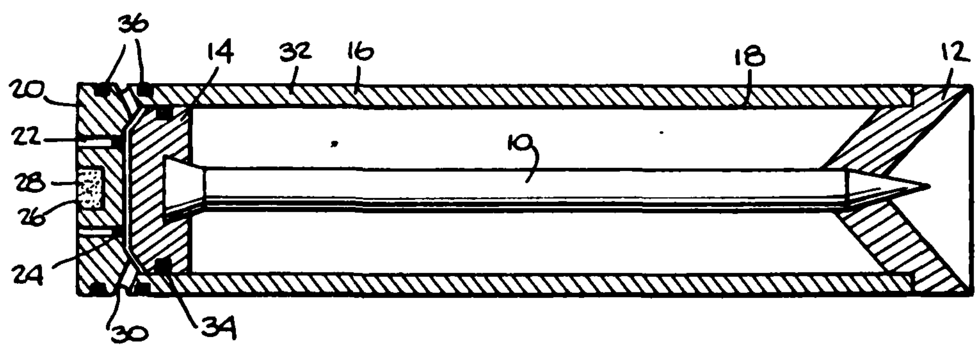


Fig.1.

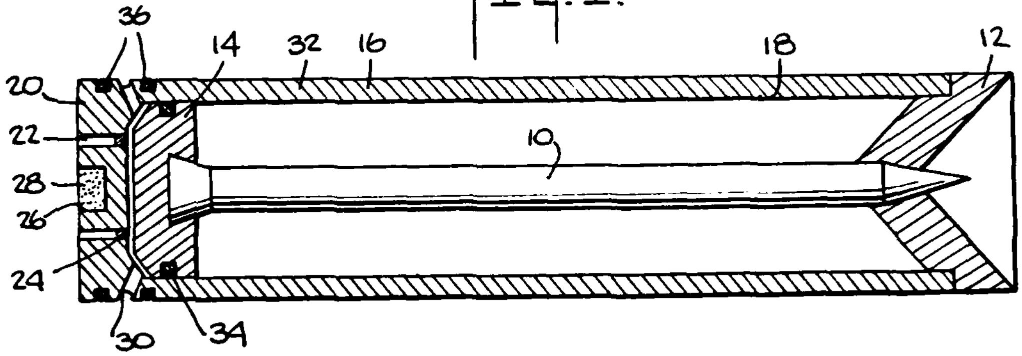


Fig.3.

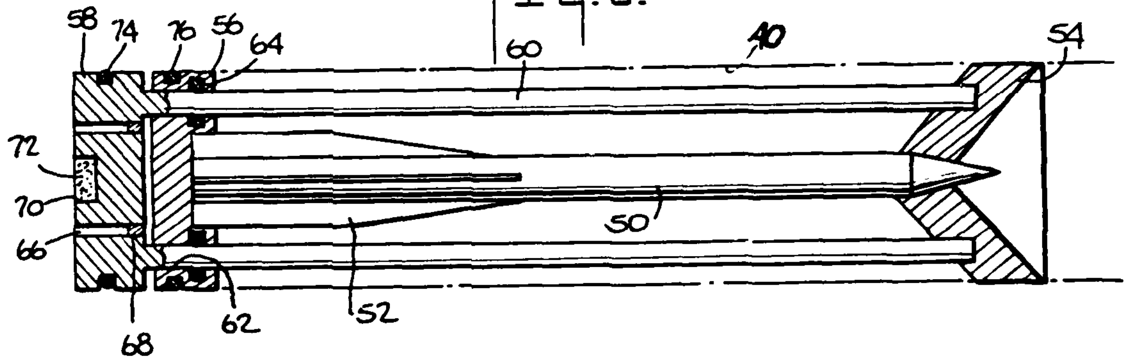
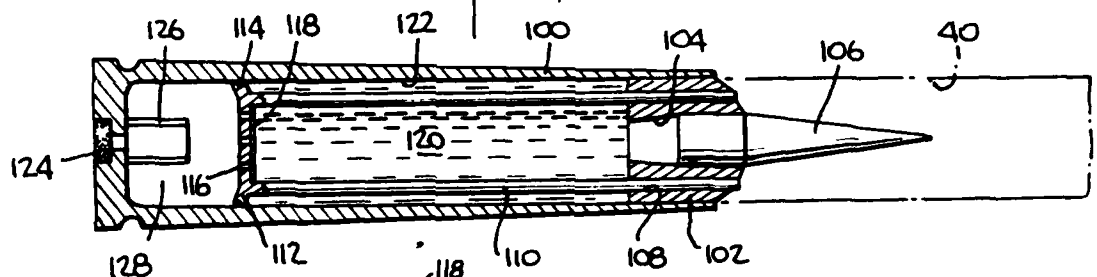


Fig.4.



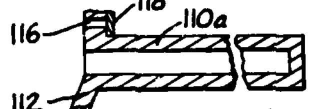


Fig.4a.

Fig.5.

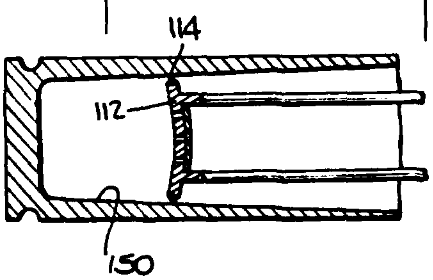
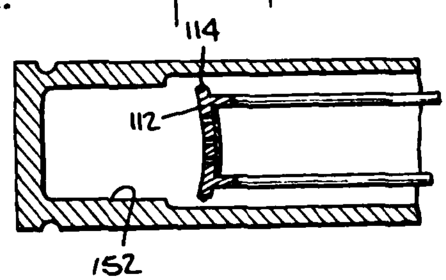


Fig.6.



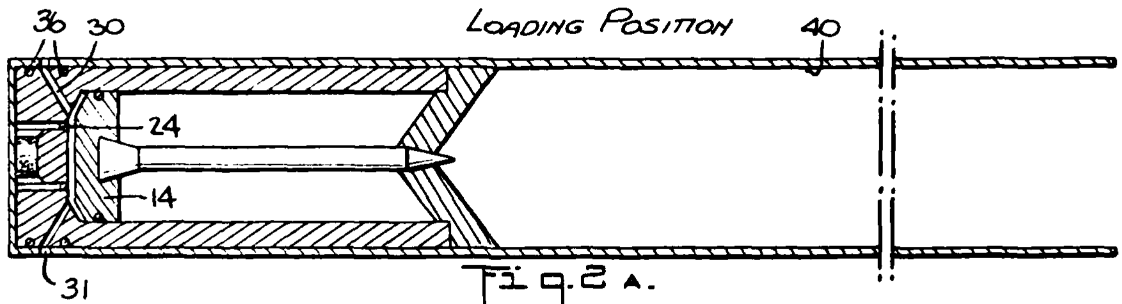


Fig. 2A.

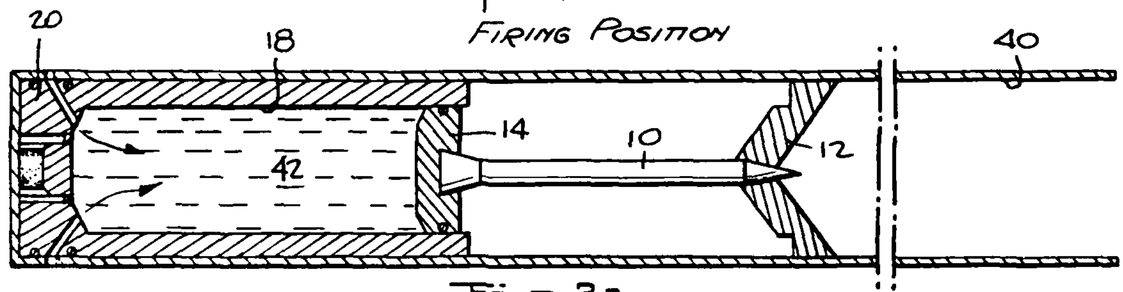


Fig. 2B.

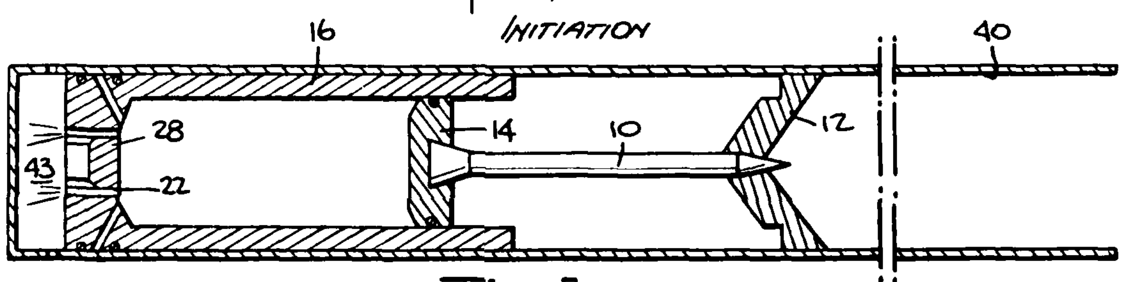


Fig. 2C.

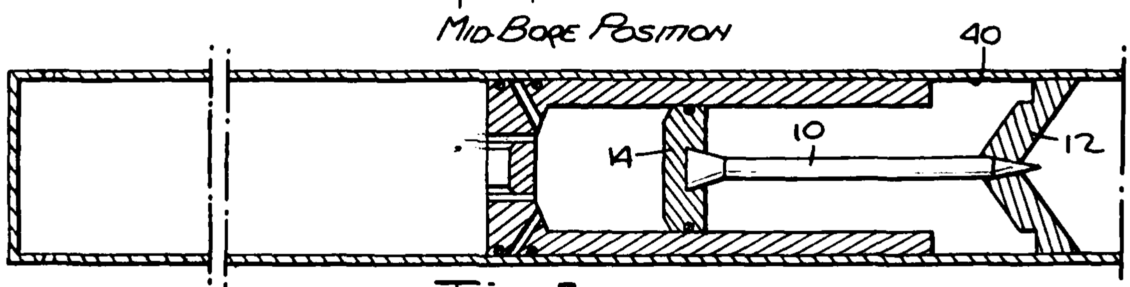


Fig. 2D.

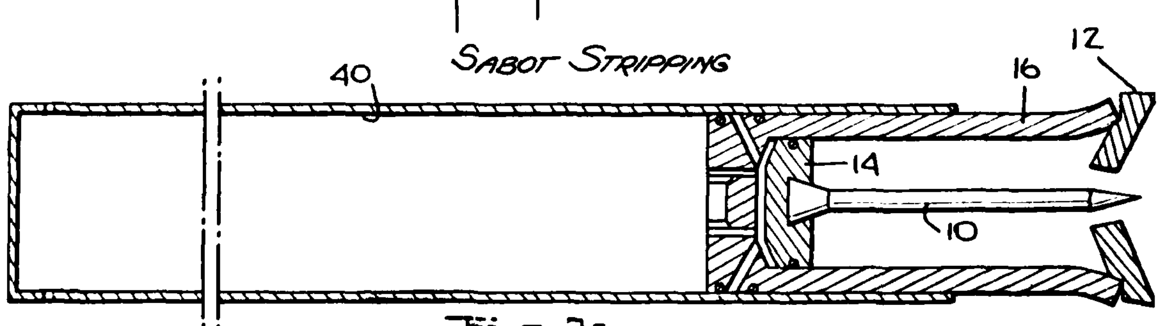


Fig. 2E.

Fig. 8.

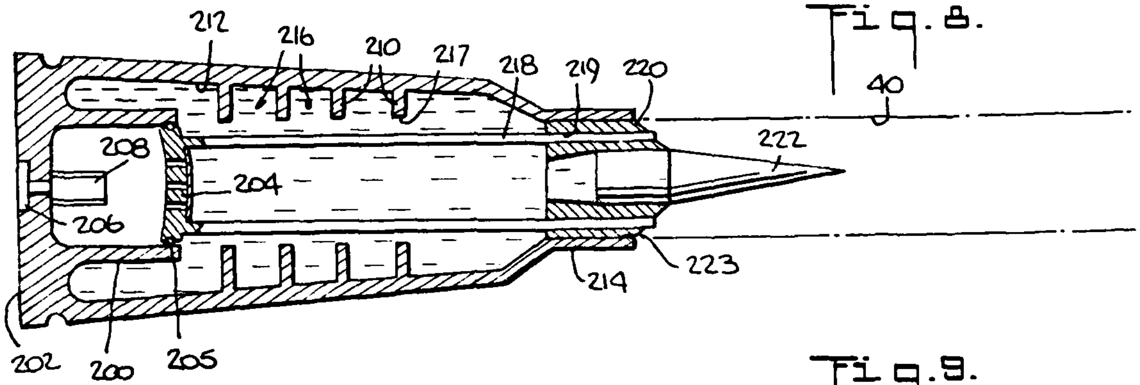


Fig. 9.

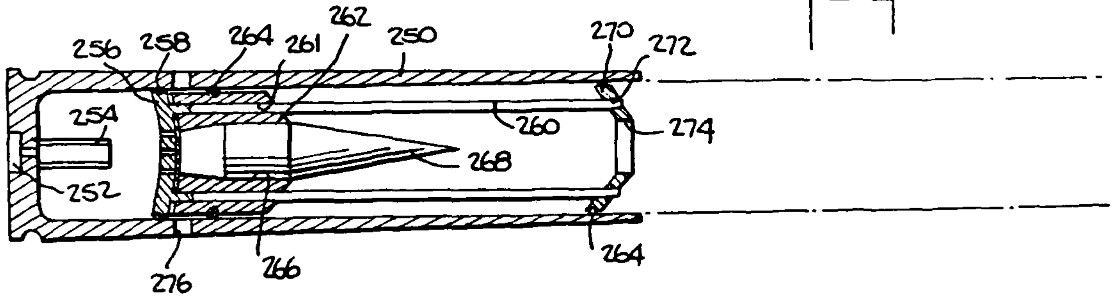


Fig. 10.

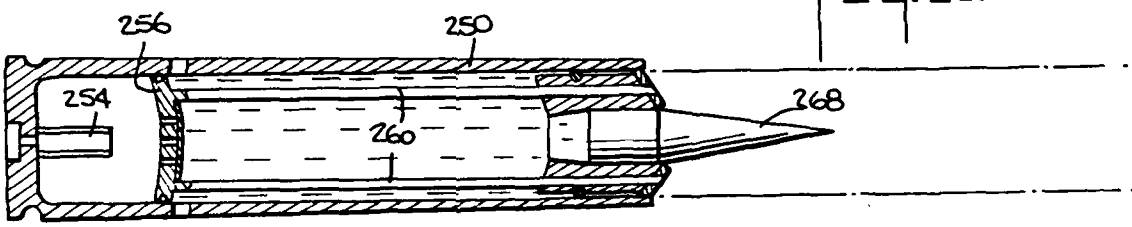
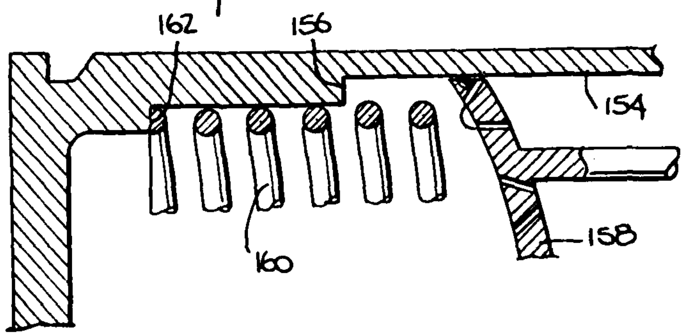


Fig. 7.



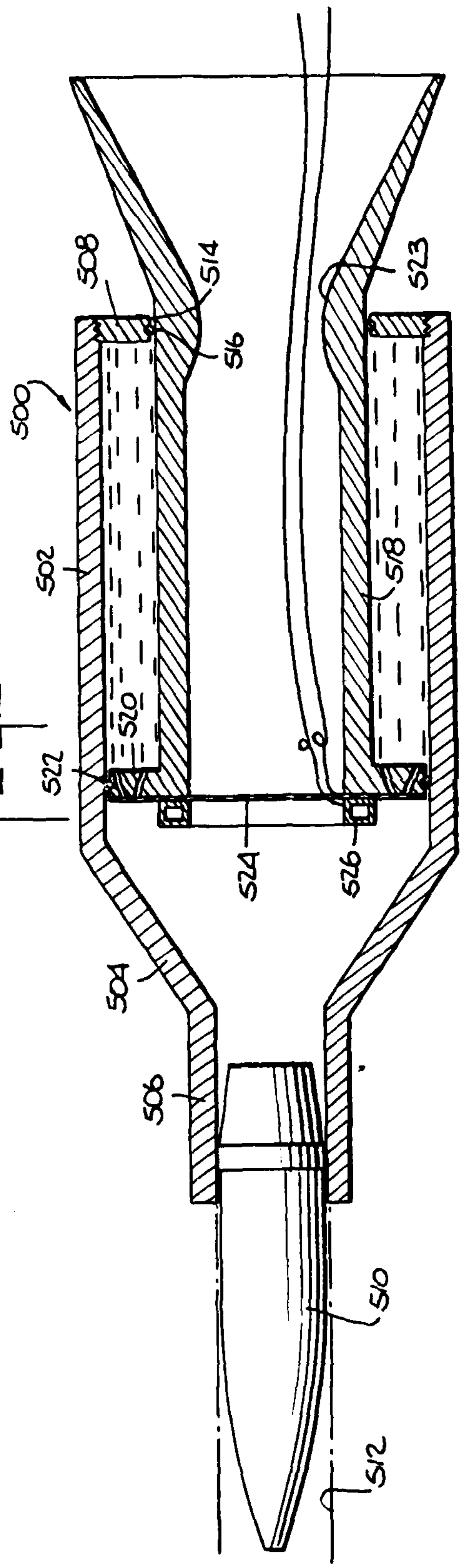

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Fig.15.

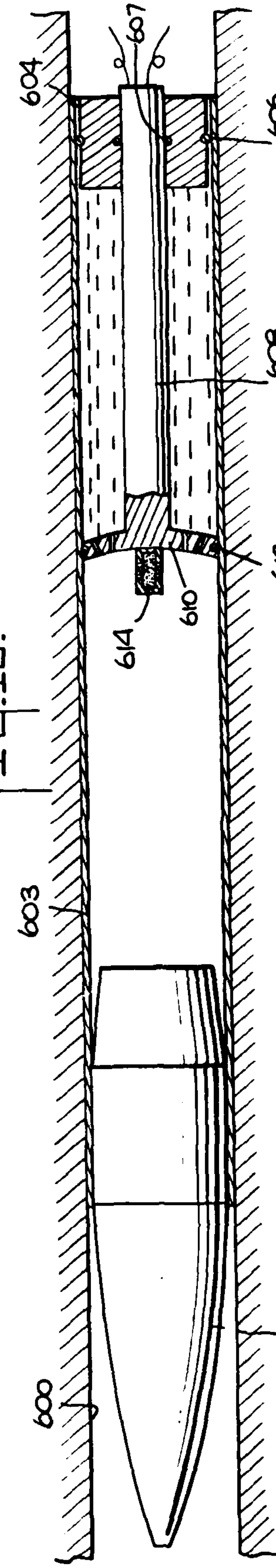
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Fig.16.

UNITED STATES PATENT OFFICE

CERTIFICATE OF CORRECTION

Patent No. 4,063,486 Dated Dec. 20, 1977

Inventor(s) Eugene Ashley

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

Column 1, line 9 change "employed" to --employing--, line 40 change "tothe" to --to the--.
Column 2, line 50 change "lauched" to --launched--.
Column 3, line 35 change "lauching" to --launching--.

Signed and Sealed this

Fifth Day of *December 1978*

[SEAL]

Attest:

RUTH C. MASON
Attesting Officer

DONALD W. BANNER
Commissioner of Patents and Trademarks

LIQUID PROPELLANT WEAPON SYSTEM

This application is a continuation of Ser. No. 469,507, filed May 13, 1974, now abandoned.

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates to weapon systems employed a liquid propellant, and particularly to such systems wherein the propellant is continuously pumped into the combustion chamber as the projectile advances along the firing bore.

2. Prior Art

Weapons systems providing traveling charge effects on projectiles, or rockets, or other related systems, are shown, for example, in U.S. Pat Nos. 3,431,816; 3,411,403; 3,459,101; 3,496,827; 3,601,056; 3,613,499; 3,628,457; 3,648,616; 3,665,803; 3,696,749; 3,698,321; 3,712,171; and 3,728,937. In a final report for the Bureau of Ordnance, Department of the Navy, under Contract NOrd 16217 Task 1, dated September 1, 1957, work was described on a propellant carrying projectile. "This projectile contained approximately 100 grams of a hydrazine, hydrazine nitrate, water monopropellant (63, 32, and 5% by weight respectively). Upon ignition of the primary bipropellant charge in the breech, regenerative injection of the bipropellants progresses in the usual manner, and the projectile is accelerated. The accelerating forces upon the projectile components are so adjusted as to produce relative motion between the projectile body and the center plunger. This motion expels the extrapped monopropellant rearward past the fragile seal disk into the hot combustion chamber gases, where it burns while the projectile is accelerated." The projectile apparently comprised a forward solid cylindrical projectile whose outer wall engaged the inner wall of the firing bore, an intermediate, longitudinally central rod journaled through a bore in the projectile, and an aft sealing disk fixed tothe rod and whose periphery engaged the inner wall of the firing bore. The monopropellant was trapped between the forward cylindrical projectile and the aft disk within the firing bore. Solid primary charges were also used in lieu of liquid primary charges. A separate static sealing disk was also used in lieu of the peripheral seal on the aft sealing disk.

SUMMARY OF THE INVENTION

It is an object of this invention to provide a gun and ammunition system for lauching rod-shaped projectiles at high velocity.

It is an additional object to provide such a system utilizing liquid propellants.

A feature of this invention is the provision of a gun and ammunition system utilizing a round of ammunition which contains a supply of liquid propellant and after ignition pumps this propellant into the combustion chamber of the gun.

An additional feature of this invention is the provision of a gun and ammunition system utilizing a round of ammunition carrying a relatively narrow diameter and relatively high mass projectile in a relatively wide and relatively low mass sabot, which is initially accelerated by a primary propellant charge in the combustion chamber aft of the projectile and which is subsequently accelerated by a secondary propellant charge in the

round which is passed during a relatively extended period of time to the combustion chamber.

BRIEF DESCRIPTION OF THE DRAWING

These and other objects, features and advantages of this invention will be apparent from the following specification thereof taken in conjunction with the accompanying drawing in which:

FIG. 1 is a view in longitudinal cross-section of an idealized round of ammunition having a sabot and a system to regeneratively pump liquid propellant, the round is here shown in its telescoped, minimum length configuration, without liquid propellant;

FIGS. 2A through E respectively illustrate, within the gun bore, the

A. before charging with liquid propellant configuration,

B. after charging with liquid propellant and ready for initiation of the primer configuration,

C. shortly after initiation and commencement of injection of liquid propellant into the combustion chamber configuration,

D. midbore configuration, and

E. bore exiting and sabot stripping configuration, in the sequence of operations of the round of FIG. 1.

FIG. 3 is a view in longitudinal cross-section of a second embodiment of this invention;

FIG. 4 is a view in longitudinal cross-section of a third embodiment of this invention;

FIG. 4*a* is a detail of a variant of the embodiment shown in FIG. 4;

FIGS. 5 and 6 are views in longitudinal cross-section of a fourth embodiment of this invention;

FIG. 7 is a view in longitudinal cross-section of a fifth embodiment of this invention;

FIG. 8 is a view in longitudinal cross-section of a sixth embodiment of this invention;

FIGS. 9 and 10 are views in longitudinal cross-section of a seventh embodiment of this invention;

FIGS. 11, 12 and 13 are views in longitudinal cross-section of an eighth embodiment of this invention;

FIG. 14 is a view in longitudinal cross-section of a ninth embodiment of this ivention;

FIG. 15 is a view in longitudinal cross-section of a tenth embodiment of this invention; and

FIG. 16 is a view in longitudinal cross-section of an eleventh embodiment of this invention.

DESCRIPTION OF THE EMBODIMENTS

Rod shaped penetrators lauched at high velocities from medium caliber guns are effective against some types of armor. Since rod penetrators are characteristically long and thin, sabot launching techniques are conventionally employed. The sabot in this case is essentially a light weight piston of diameter larger than the penetrator, and which supports the heavier penetrator. In the lauching or firing process, the combustion gas acts against the area of the full diameter of the sabot, rather than against the rod alone, in accelerating the two in combination.

Liquid propellants have several desirable characteristics, such as relatively low flame temperature and ease of storage and handling. A major problem in the use of liquid propellants lies in the control of the ballistic process in the combustion chamber. Propellant can be either placed in the chamber before firing and then be ignited; or it can be metered into the chamber during the combustion process. The first mentioned, sometimes

called preloading, is easier to do mechanically, but permits little control over burning after ignition. U.S. Pat. No. 3,763,739 issued to D. P. Tassie on Oct. 9, 1973, discloses a gun system of this type. The second mentioned, sometimes called forced injection, permits control over the rate of burning through control over the rate of introduction of the propellant, but involves extremely high pumping pressures. Such high pressures pose stringent requirements on seals, fittings and structural components. If the energy for forced injection is to be supplied from an external source, the power requirements are very high. For example, the power required to pump three cubic inches of propellant across a pressure drop of 10,000 psi in 20 milliseconds is 227 hp. This can be averaged over a larger period in an actual gun to lower the peak value, but the power requirement is still unreasonable.

An effective solution to the power requirement for pumped injection is to utilize the combustion chamber pressure itself as the source of energy for pumping. Called regenerative injection, this scheme uses a differential area piston for each propellant. The larger end of the piston is acted on by the chamber pressure, and the smaller end pressurizes the propellant to be injected. The difference in areas generates a propellant pressure sufficiently higher than the chamber pressure to achieve the desired rate of injection.

FIRST EMBODIMENT

Turning now to FIG. **1**, a first embodiment of the invention is shown as an idealized round of ammunition having a sabot and regenerative, liquid propellant pumping system, for use in a gun which will fill the round with propellant before firing. The penetrator **10** is here shown as a rod which upon lauching will be drag stabilized. The sabot is a three piece assembly, comprising an annular nose stabilier **12** fixed to the forward end of the penetrator, a circular pusher-plate **14** fixed to the aft end of the penetrator, and a cylindrical body **16.** The body **16** has an internal bore **18** closed at its aft end **20,** which bore receives the plate **14.** The aft end **20** serves as an injector plate and has a plurality of longitudinal bores **22** therethrough serving as injection passageways. Each bore is obturated by a respective plug **24.** An aft recess **26** receives a primary propellant charge, here shown as a solid primer **28.** One or more substantially radially oriented bores **30** pass through the side wall **32** of the body into the interface between the plate **20** and the plate **14,** to serve as propellant fill passageways. An annular seal **34** is provided on the periphery of the plate **14,** and a pair of annular seals **36** are provided on the periphery of the body **16** straddling the fill passageways.

The plugs **24** may be embodied as relief valves, individual plugs, a burst diaphragm fixed to the forward face of the injector plate, or simply portions or the bore material not fully drilled through, all of which will shear or open at the desired pressure level.

The penetrator and sabot assembly may be preloaded with liquid propellant through the fill passageways, which are then plugged, before being placed in the gun. Alternatively, the assembly may be placed in the firing bore **40** of the gun and then loaded with propellant. The actual firing process is the same for each scheme, and loading within the gun will be discussed with respect to FIGS. 2A through 2C.

As shown in FIG. 2A, the penetrator and sabot assembly, still without its propellant charge, has been placed into the breech of a gun barrel and the breech has been closed. The fill passageways **30** are aligned with suitable fill ports **31** in the breech wall of the gun, such as are shown in U.S. **3,763,739,** supra, which must incorporate high pressure fill valves or check valves which can withstand firing pressure. These passageways serve as means for providing liquid propellant to the round of ammunition in the firing bore.

As shown in FIG. 2B, propellant is pumped into the interface between the injector plate **20** and the pusher plate **14,** progressively pushing the pusher plate forward within the bore **18** to create an injection volume **42** which receives a complete charge. Stops can be provided to halt the forward advance of the nose stabilizer, or preferably, the charge can be metered. The round is shown fully charged and ready for firing.

As shown in FIG. 2C, firing is initiated by setting off the primer, which rapidly generates a small volume of high pressure, hot gas in the space **43** aft of the injector plate which serves as the combustion chamber. This high pressure aft of the loaded round produces an immediate acceleration of the complete round. The overall force producing the acceleration, which force is equal to the chamber pressure times the chamber cross-sectional area, is exerted against the aft face of the injector plate. The penetrator and sabot assembly has a relatively high weight relative to the weight of the body **16** with a correspondingly relatively high inertia. A portion of the accelerating force is absorbed in accelerating the body **16** per se, but the remainder of the accelerating force is transmitted by the forward surface of the injector plate against the charge of liquid propellant. The resultant pressure developed in the liquid is the transmitted force divided by the liquid or injection volume cross-sectional area. When the ratio of the areas of the aft face of injector plate and the injection volume, and the body weight and the total round weights are properly predetermined, a liquid pressure will be generated which is higher than the chamber pressure as follows:

$$(P_L/P_C) = (A_C/A_L)\,[1-(W_B/W_{TOT})]$$

where

P_L is liquid pressure,
P_C is chamber pressure,
A_C is chamber area,
A_L is liquid area,
W_B is body weight, and
W_{TOT} is the sum of the body, the liquid and the penetrator and sabot assembly weights.

The difference between the two pressures P_L and P_C is the driving force which can be utilized for regenerative injection.

The plugs **24** are designed to open at a predetermined difference in pressure between the interior volume and the combustion chamber. These plugs serve as a pressure sensitive obturating means. As shown in FIG. 2C, when this difference is reached, the plugs will open and propellant will flow into the chamber. The injection passageways **22** serve to atomize or break up the propellant streams through techniques similar to those used in rocket injector design. As the propellant streams initially encounter the hot primer gases they ignite, generating more hot gas. Incoming propellant continues to ignite and the process becomes self sustaining, and generates increasing chamber pressure, which accelerates the process. The process continues until the propellant is expended. Meanwhile, the whole round is being ac-

celerated along the bore by what is in effect, a traveling charge. FIG. 2D shows the round at mid-bore length with the propellant partially expended.

As the round leaves the muzzle, the sabot fore and aft supports are stripped from the penetrator which continues on its course. FIG. 2E shows the nose stabilizer **12** acting under wind forces to open the body **16** and free the penetrator.

The entire body **16** is here shown as engaging the rifling of the bore **40** to provide spin to the entire round if a spin stabilized projectile is used. Alternatively a lesser annular portion of the body may engage the rifling.

SECOND EMBODIMENT

Frictional forces are developed between the body **16** and the interior wall of the bore **40** as the round is launched, which are a function of the materials of the body **16** and the bore **40** of the gun barrel. An alternative embodiment which minimizes such frictional forces is shown in FIG. **3**.

The penetrator **50** is here shown as a rod which is stabilized by a plurality of fins **52**. The sabot is a three piece assembly comprising an annular nose stabilizer **54** fixed to the forward end of the penetrator, a circular pusher-plate **56** fixed to the aft end and an injection plate **58** having a plurality of forwardly, longitudinally extending, integral rods **60**. The pusher plate **56** has a like plurality of longitudinal bores **62** with respective annular seals **64** each passing a respective one of the rods **60**. The injector plate **58** also has a plurality of longitudinal bores **66** therethrough each obstructed by a respective plug **68**, and an aft recess **70** receiving a primary propellant charge **72**, all similar to the embodiment of FIG. **1**. These plugs **68** serve as a pressure sensitive obturating means. An annular seal **74** is provided in the periphery of the injector plate, and an annular seal **76** is provided in the periphery of the pusher plate. This penetrator and sabot assembly is disposed in the gun for filling with propellant with the fill ports in the breech wall of the gun aligned with the interface between the injection plate and the pusher plate.

The use of the rods **60** upon which the pusher plate can slide permits the omission of the body structure, so that only the peripheries of the pusher plate, the injector plate and the stabilizer need contact the wall of the barrel bore **40**. The liquid propellant is contained between the pusher plate, the injector plate and the wall of the barrel bore. The necessary differential in areas is provided by the total cross-sectional areas of the rods **60**. The rods provide an added advantage in the sabot stripping phase of the launching cycle as they are relatively weaker and therefore easier to deflect radially outwardly than the equivalent cylindrical body **16**.

Both of the embodiments described above provide the following advantages:

1. Controlled injection is achieved through regenerative pumping action;
2. The inertia of the projectile itself is the source of the pumping force;
3. The injection mechanism is incorporated into the penetrator and sabot assembly, with very little effect on the gun design,
4. A traveling charge effect is achieved;
5. The injection system and high pressure seals are used only once for each shot and are then discarded.
6. The sabot and projectile assemblies may be stored and transported as essentially inert, considering the primer to be relatively insignificant. The assemblies do not become active until the introduction of the propellant. This can be delayed until after chambering and locking in the gun.

The specification so far has dealt whith idealized projectile and sabot assemblies and their launching techniques. Cartridges embodying such assemblies may be provided in at least several different configurations.

THIRD EMBODIMENT

FIG. **4** shows the simplest pre-filled cartridge case embodiment. The projectile and sabot assembly are crimped into a cartridge case **100**. The assembly comprises a forward annulus **102** which serves as a pusher plate and has a central bore **104** receiving a spin stabilized projectile **106** and a plurality of bores **108** disposed in an annular row, each receiving a respective one of a like plurality of rods **110** which are respectively fixed to an injector plate **112**. The injector plate has an annular seal **114** fixed to its periphery and a plurality of longitudinal injection passageways **116** which are closed by a diaphragm **118** fixed to the forward face of the plate. The liquid propellant charge **120** is contained between the annulus **102**, the plate **112** and the inner wall **122** of the case **100**. The bore of the case includes an external primer **124** in communication with an internal booster tube **126** disposed in the combustion chamber **128** which is defined by the base of the case, the injector plate and the interior wall of the case. Upon ignition the injector plate and its rods move forwardly relative to the annulus, rupturing the diaphragm and injecting propellant into the combustion chamber. This diaphragm serves as a pressure sensitive obturating means. The inner wall **122** of the case is cylindrical and coplanar with the inner wall **40** of the bore of the gun barrel, so that the forward annulus and the injector plate smoothly leave the case and ride along the gun bore. The forward annulus may be made up of segments to provide ready rupture and release of the projectile when the assembly leaves the gun bore.

The injector plate **112** may be made of arched cross-section for a greater strength of weight ratio.

The rods **110** may be replaced with hollow tubes ***110a***, as shown in FIG. ***4a***; which are closed at their forward ends and open at their aft ends so that the interior volume of each tube communicates with and is at the same pressure as the combustion chamber **128**. This permits the use of a thin wall tube whose wall thickness becomes progressively thinner from front to rear; since as the length of the tube exposed forwardly of the annulus **102** into the atmosphere increases, the combustion chamber pressure decreases.

FOURTH EMBODIMENT

In the embodiments discussed above, all of the injection of the propellant into the combustion chamber takes place through the passageways of the injector plate. An enlarged "Taylor cavity" will be formed by providing a tubular cylinder of propellant liquid in the combustion chamber as said chamber is being enlarged by the forward movement of the injector plate. The "Taylor cavity" provides a liquid-gas interface for combustion. This is accomplished by providing a variable internal diameter in the case which increases towards the mouth of the case. As shown in FIG. **5**, the bore **150** of the case may be tapered, or as shown in FIG. **6**, the

bore **152** of the case may be stepped to provide a variable, increasing, orifice for the liquid propellant around the periphery of the injector plate.

FIFTH EMBODIMENT

The injector plate should be prevented from moving aft under impulse loads exerted by the liquid propellant under conditions of vigorous handling or in the event a cartridge is dropped on its base. This can be accomplished by providing stops on the displacement rods aft of their engagement with the injector plate; a step can be provided in the interor wall of the case aft of the injector plate; or the injector plate may be fastened to the interior wall of the case by a weak joint which will rupture under the firing forces. To further minimize the effects of handling loads the stops may be made resilient. As shown in FIG. 7, the interior wall **154** may be provided with a step **156** to abut the outer margin of the injector plate **158**. A helical spring **160** may be captured between an additional step **162** and the injector plate to resiliently fix the inputs plate and to permit it to move aft slightly before abuting the positive shoulder **156**.

SIXTH EMBODIMENT

In the embodiment shown in FIG. 8, a prefilled case is provided which has an interior annular wall **200** extending from the base **202** which together with the injector plate **204** and its peripheral seal **205** defines an initial combustion chamber. An external primer **206** communicates with an internal booster **208** disposed in the initial combustion chamber. A plurality of rigid, spaced apart, partitions **210** extend inwardly from the interior wall **212** of case which is tapered progressively inwardly from the base to the neck **214** to provide a series of compartments **216** of decreasing volume, each opening into a central bore **217**. As described with respect to *FIG. 4. the injector plate is fixed to rods 218* which are journaled through respective bores **219** in an annulus **220** which retains the projectile **222**. The bore **223** of the neck is coplanar with the gun bore **40**. Liquid propellant is stored forward of the injection plate in the compartments **216** and in the central bore. The propellant in the central bore is injected into the combustion chamber by the injection plate as discussed with respect to FIG. 4. The propellant in each open compartment **216** tends to remain in place and to ignite as its compartment is exposed to the initial combustion chamber as the injection plate moves forward, also providing a "Taylor Cavity" effect.

SEVENTH EMBODIMENT

FIGS. **9** and **10** show a dry loaded cased cartridge embodiment, similar to the case of FIG. **4**. The cartridge is provided with a case **250** having a primer **252** communicating with a booster charge **254**, and a projectile and sabot assembly. The sabot includes an injector plate **256** having a peripheral seal **258** and a plurality of longitudinally extending rods **260** fixed thereto and respectively journaled through bores **261** in an annulus **262** which has a peripheral seal **264** and an axial bore **266** receiving a projectile **268**. A stabilizing ring **270** is retained against non-firing loads aft of the mouth of the case as by cementing or crimping and has a like plurality of bores **272** journaling said rods **260** and an axial bore **274** adapted to pass the projectile. A plurality of radial bores **276** are disposed through the case in an annular row to serve as propellant filling passageways. In the stored configuration, as shown in FIG. 9, the annulus **262** is nested aft, close to the injector plate, without any liquid propellant, and the seals **258** and **264** straddling the row of bores **276**. After the case has been loaded into the gun and the gun breech has been locked, the liquid propellant charge is pumped through aligned ports in wall of the breech of the gun as described with respect to FIG. 2B. The injector plate is prevented from aftward movement by suitable means, such as the stops described with respect to FIG. 7. As the liquid propellant charge is pumped into the interface between the injector plate and the annulus, it forces the annulus forward until it is stopped by the stabilizing ring, which provides an automatic metering device for the filling operation.

Both pre-loaded and dry-loaded cased cartridges share the following advantages:

1. Sealing of the breech is provided by the case.
2. The priming system is conveniently provided for each round.
3. A misfired round can be completely extracted by extracting the case.

The dry-loaded cartridge has the additional following advantages for shipping and handling:

1. The projectile is telescoped within the case for shipping and for loading into the gun. This minimizes the length of the parts to be handled.

2. The cartridge is relatively safe. In the absence of propellant, the primer and booster are the only combustible components present.

3. The propellant is loaded separately through control valves and piping. This can be controlled remotely if necessary.

4. The breech is closed before the propellant is charged into the cartridge, providing additional safety.

EIGHTH EMBODIMENT

FIGS. 11 and 12 show a dry loaded uncased cartridge, which is loaded, locked, filled and fired in a manner similar to the cased cartridge of FIGS. **9** and **10**. The sabot and projectile assembly comprises an injector plate **300** having a peripheral seal **302** and a plurality of longitudinally extending rods **304** fixed thereto and respectively journaled through bores **305** in an annulus **306** which has a peripheral seal **307** and an axial bore **308** receiving a projectile **310**. A stabilizing ring **312** has a like plurality of bores **314** journaling said rods **304** and an axial bore **316** adapted to pass the projectile. As shown in FIG. **13**, a primer and booster assembly comprises a sleeve **318** which cemented to the aft face of the injector plate **300**. The sleeve is molded of solid propellant, of sufficient strength to provide a small combustion chamber **320** initially, but which will ultimately burn. A combustible primer **322** is fixed in a cup **324** in the exterior of the base of the sleeve and which communicates by a passageway **326** with the combustion chamber **320**. The forward end of the sleeve is closed with a plug **328** which may be cemented. Radially extending flame passageways **330** are provided through the walls of the sleeve. These passageways are initially closed, as by plugs, being only partially formed through, or covered by a diaphragm. Loose powder is disposed in the combustion chamber.

The length of the primer and booster assembly is made equal to the length of the combustion chamber of the gun. When the cartridge is chambered and the breech is locked, the primer **322** is adjacent the face **332** of the breech block, and may be ignited by a conventional percussion firing pin **334**, or electrical firing

means. The primer ignites the loose powder immediately, generating hot gases which rupture the flame passageway closures and pass into the combustion chamber. The molded combustible sleeve burns more slowly than the loose powder, but eventually all is consumed. The hot gas initiates the regenerative liquid propellant injection process as described previously.

The dry-loaded caseless cartridges have the following advantages:

1. The system is completely combustible. The gun chamber is completely empty after each shot.
2. The primary system is an integral part of the cartridge as supplied to the gun.
3. The primary system may be fabricated using conventional caseless ammunition technology.

NINTH EMBODIMENT

FIG. 14 shows a recoiless gun embodiment of a caseless cartridge similar to that shown at FIG. 12. The sabot and projectile assembly comprises an injector plate 400 having a peripheral seal 402 and a plurality of longitudinally extending rods 404 fixed thereto and respectively journaled through bores 405 in an annulus 406 which has a peripheral seal 408 and an axial bore 410 receiving a projectile 412. A stabilizing ring 414 has a like plurality of bores 416 journaling said rods 404 and an axial bore 418 adapted to pass the projectile. A priming system comprising a sleeve 420 which may be molded of solid propellant is cemented to the aft face of the injector plate 400. The sleeve has radially extending flame passageways 422 which are initially closed and contains loose powder which may be ignited by an electrical firing system 424. A frangible diaphragm 426 is cemented to the aft end of the sleeve. The initial combustion chamber is provided within the sleeve, and the subsequent combustion chamber is defined between the injection plate and the diaphragm. The diaphragm is adapted to burst at a pressure which is high enough to insure that initiating combustion has been achieved.

The gun 427 includes suitable ports 428 to pass liquid propellant to the interface between the injection plate 400 and the annulus 406. The gun also includes a converging/diverging nozzle 430 in lieu of the conventional closed breech. This nozzle may be of the type shown, for example, in U.S. Pat. Nos. 2,444,949, 2,696,760, 2,790,353 and 3,610,093. The nozzle provides an expansion chamber and a venturi orifice therein to allow a sufficient amount of the combustion gases to expand and escape rearwardly, thereby stabilizing the gun against recoil. The nozzle may be made separable from the breech to permit loading of the cartridge. FIG. 14 shows the annulus 406 midway in its forward advance during the loading with liquid propellant.

TENTH EMBODIMENT

FIG. 15 shows a recoiless gun embodiment of a cased, preloaded cartridge. The cartridge includes a case 500 having a side 502, a shoulder 504, a neck 506 and a base plate 508 threaded into the side 502. A projectile 510 is crimped into the neck, and is received in the firing bore 512 of the gun. The base plate 508 has central bore 514 with an annular seal 516 to pass the neck 518 of a tubular injector and nozzle assembly. This assembly includes an annular injection plate 520 having an annular seal 522 integral with the forward end of the neck and a converging/diverging nozzle 523 integral with the aft end of the neck. A frangible diaphragm 524 is cemented over the forward end of the tube and an annular priming system 526 is cemented onto the diaphragm. The priming system is similar to a torus of square cross-section, having flame passageways, loose powder, and an electrical firing system whose leads may be brought through the diaphragm and out the bore of the neck and the nozzle or through the sidewall of the case. Liquid propellant is stored in the chamber defined by the base plate 508, the injection plate 520, the side 502, and the neck 518.

This embodiment does not provide a traveling charge. Ignition of the priming system ruptures the diaphragm and moves the injector and nozzle assembly aft, which in turn provides regenerative pumping forwardly of the liquid propellant through the passageways of the injector plate.

ELEVENTH EMBODIMENT

FIG. 16 shows a recoiless gun embodiment of a cased cartridge employing a reaction or compensating mass of the type shown in U.S. Pat. No. 1,108,716. This embodiment does not provide a traveling charge. In its simplest form, the gun includes a firing bore 600 open at both ends. A projectile 602 and an injector and reaction mass assembly are secured in a tubular cartridge case 603 which is disposed in the bore 600. The assembly comprises a solid reaction mass 604 having a peripheral seal 606 and a central bore with an annular seal 607, in which is journaled a rod 608 to whose forward end is fixed an injection plate 610 having a peripheral seal 612. A priming system 614 is fixed to the forward face of the injection plate. The priming system may comprise a sleeve molded of combustible material with flame passageways, filled with loose powder, and having an electrical firing means which may be brought out through the rod 608. Firing is initiated by hot gases generated by the priming system in the combustion chamber defined between the projectile and the ignition plate. The liquid propellant is stored in the chamber defined between the injection plate and the reaction mass, and serves as part of the total reaction mass, so that the solid mass actually ejected out the breech of the gun is less than required by fixed, solid propellants. In a caseless embodiment, not shown, the case is omitted and the liquid propellant is injected as discussed with respect to FIG. 2B.

It is contemplated that the inventive concepts hereinabove described may be variously otherwise embodied and combined without departing from the inventive principles included and intended to be covered by the appended claims, except insofar as limited by the prior art.

What is claimed is:

1. A fixed round of ammunition comprising
   - a cartridge case including a tubular side wall having an open forward end and a closed base end, and a gas generating means supported by said base end;
   - a relatively high mass projectile means disposed within and obturating said open end of said case;
   - a relatively low mass piston means disposed within said case longitudinally spaced from and aft of said projectile means and journaled for longitudinal movement in said case, and having
     - an aft face of relatively large cross-sectional area and a forward face of relatively small cross-sectional area,
     - a passageway therethrough communicating between said aft and forward faces of said piston means, and

pressure sensitive obturating means for obturating said passageway and for opening said passageway upon a predetermined pressure being provided on said forward face;

said gas generating means disposed aft of said piston means;

said piston means coupled to said projectile means for joint longitudinal displacement with respect to said case and for relative longitudinal displacement with respect to said projectile means upon functioning of said gas generating means.

2. A fixed round of ammunition according to claim 1 wherein:

said projectile means has an aft face within said cartridge case;

said tubular side wall of said cartridge case has a bore therethrough communicating to the forward interior face of said base end of said case and said aft face of said projectile means.

3. A fixed round of ammunition according to claim 1 wherein:

said passageway has the characteristic of atomizing liquid propellant passing therethrough and out said aft face of said piston means.

4. A fixed round of ammunition according to claim 1 further including:

a plurality of longitudinally extending alignment rods disposed in a transverse annular row, each fixed to one member of said group consisting of said piston means and said projectile means, and journaled for relative longitudinal movement with respect to the other member of said group.

5. A fixed round of ammunition according to claim 1 wherein:

the internal diameter of the aft portion of said side wall of said cartridge case is equal to the diameter of said piston means, and

the internal diameter of the forward portion of said side wall is greater than said diameter of said piston means, thereby, when said piston means is in said forward portion of said case, providing an annular gap between said piston means and said side wall.

6. A fixed round of ammunition according to claim 1 further including:

resilient stop means disposed in said cartridge case for resiliently limiting aftward movement of said piston in said cartridge case.

7. A fixed round of ammunition according to claim 1 wherein:

said projectile means comprises a relatively low mass sabot supporting a relatively high mass projectile, said sabot sealing said open end of said case.

8. A fixed round of ammunition according to claim 1 wherein:

a quantity of liquid propellant is disposed and sealed within a chamber defined by said case, said piston means and said projectile means.

9. A fixed round of ammunition according to claim 8 wherein:

said passageway has the characteristic of atomizing liquid propellant passing therethrough and out said aft face of said piston means.

10. A fixed round of ammunition according to claim 1 further including:

a plurality of longitudinally extending alignment tubes disposed in a transverse annular row, each tube having an aft end fixed to said piston means and open to the aft face of said piston and closed at its forward end, and journaled through a like plurality of longitudinal bores disposed in a transverse annular row in said projectile means.

11. A fixed round of ammunition according to claim 10 wherein:

said projectile means comprises a relatively low mass sabot supporting a relatively high mass projectile, said sabot sealing said open end of said case and having said bores in which are journaled said tubes.

12. A fixed round of ammunition according to claim 1 wherein:

the internal diameter of the aft portion of said side wall of said cartridge case is equal to the diameter of said piston means, and

the forward portion of said cartridge case includes a plurality of annular compartments, each inwardly open and defining a central bore through which said piston means passes.

13. A fixed round of ammunition according to claim 12 further including:

a quantity of liquid propellant disposed within said annular compartments.

14. A fixed round of ammunition comprising:

a cartridge case having a side wall defining a tube;

a base, having a relatively low mass, closing the aft end of said tube, and having an interior forward face and an exterior aft face,

a gas generating means communicating with said aft face of said base,

a projectile means, having a relatively high mass, disposed at least in part within said tube and obturating the forward end of said tube

said base serving as a differential piston means movable along said tube towards said projectile means, and its aft face having a relatively large cross-sectional area and its forward face having a relatively small cross-sectional area,

said base having a passageway therethrough communicating between said aft and forward faces of said base, and

pressure sensitive obturating means for obturating said passageway and for opening said passageway upon a predetermined pressure being provided on said forward face of said base.

15. A fixed round of ammunition according to claim 14 wherein:

a quantity of liquid propellant is disposed within said case and sealed between said piston means and said projectile means.

16. A fixed round of ammunition according to claim 14 wherein:

said passageway has the characteristic of atomizing liquid propellant passing therethrough and out said aft face of said piston means.

17. A fixed round of ammunition according to claim 14 wherein:

said projectile means has an aft face within said case;

said side wall of said case has a bore therethrough communicating to said forward face of said base and said aft face of said projectile means.

18. A fixed round of ammunition according to claim 17 wherein:

said passageway has the characteristic of atomizing liquid propellant passing therethrough and out said aft face of said piston means.

19. A fixed round of ammunition comprising:

a side wall defining a tube,

a base, having a relatively low mass, closing the aft end of said tube, and having an interior forward face and an exterior aft face,

a gas generating means communicating with said aft face of said base,

a projectile means, having a relatively high mass, disposed at least in part within said tube and obturating the forward end of said tube,

said base serving as a differential piston means movable along said tube towards said projectile means, and its aft face having a relatively large cross-sectional area and its forward face having a relatively small cross-sectional area,

said base having a passageway therethrough communicating between said aft and forward faces of said base, and

pressure sensitive obturating means for obturating said passageway and for opening said passageway upon a predetermined pressure being provided on said forward face of said base.

20. A fixed round of ammunition according to claim **19** wherein:

said side wall is part of a cartridge case.

21. A fixed round of ammunition according to claim **19** wherein:

said projectile means includes a sabot supporting a projectile.

22. A fixed round of ammunition according to claim **19** further including:

a plurality of longitudinally extending tubes, each having a longitudinally extending bore therein, each tube being fixed at its aft end to said base and journaled at its forward end through a corresponding longitudinally extending bore in said projectile means, the aft end of each said bore being open to said aft face of said bore, the forward end of each said bore being closed.

23. A fixed round of ammunition according to claim **22** wherein:

said projectile means includes a sabot supporting a projectile, and said bores, in which are journaled said tubes, are provided in said sabot.

24. A fixed round of ammunition according to claim **19** further including:

a plurality of rods coupled to and between said projectile means and said base, for guiding said base for relative movement towards said, projectile means.

25. A fixed round of ammunition according to claim **24** wherein:

each of said rods is fixed to said base and is journaled through a corresponding bore in said projectile means.

26. A fixed round of ammunition according to claim **25** wherein:

said projectile means includes a sabot supporting a projectile, and said bores, in which are journaled said rods, are provided in said sabot.

27. A weapon system comprising:

a gun; and

a round of ammunition;

said gun having a firing bore closed by a breech face; and

said round of ammunition is disposed in said firing bore adjacent said breech face;

said round of ammunition including a gas generating means disposed adjacent said breech face;

a relatively high mass projectile means disposed within and obturating said open end of said bore;

a relatively low mass differential piston means disposed within said firing bore longitudinally spaced from and aft of said projectile means and journaled for longitudinal movement in said firing bore, and having

an aft face of relatively large cross-sectional area and a forward face relatively small cross-sectional area,

a passageway therethrough communicating between said aft and forward faces of said piston means, and

pressure sensitive obturating means for obturating said passageway and for opening said passageway upon a predetermined pressure being provided on said forward face;

said gas generating means providing gas aft of said piston means;

said piston means coupled to said projectile means for joint longitudinal displacement with respect to said firing bore and for relative longitudinal displacement with respect to said projectile means upon functioning of said gas generating means.

28. A weapon system according to claim **27** wherein:

said gun includes means for providing liquid propellant to said round of ammunition in said firing bore between said projectile means and said piston means.

29. A weapon system according to claim **28** wherein:

said passageway has the characteristic of atomizing liquid propellant passing therethrough and out said aft face of said piston means.

30. A weapon system according to claim **27** further including:

a plurality of longitudinally extending alignment rods disposed in a transverse annular row, each fixed to one member of said group consisting of said piston means and said projectile means, and journaled for relative longitudinal movement with respect to the other member of said group.

31. A weapon system according to claim **27** wherein:

said projectile means comprises a relatively low mass sabot supporting a relatively high mass projectile, said sabot sealing said open end of said bore.

32. A weapon system according to claim **27** further including:

a plurality of longitudinally extending alignment tubes disposed in a transverse annular row, each tube having an aft end fixed to said piston means and open to the aft face of said piston and closed at its forward end, and journaled through a like plurality of longitudinal bores disposed in a transverse annular row in said projectile means.

33. A weapon system according to claim **32** wherein:

said projectile means comprises a relatively low mass sabot supporting a relatively high mass projectile, said sabot sealing said open end of said case and having said bores in which are journaled said tubes.

34. A weapon system according to claim **27** further including:

container means for containing a volume of liquid between and in contact with said forward face of said piston means and said aft face of said projectile means; and

a charge of liquid propellant disposed within said container means.

35. A weapon system according to claim **34** wherein:

said passageway has the characteristic of atomizing liquid propellant passing therethrough and out said aft face of said piston means.

36. A weapon system according to claim **34** wherein:

said container means is a cartridge case, and

the internal diameter of the aft portion of said side wall of said cartridge case is equal to the diameter of said piston means, and

the internal diameter of the forward portion of said side wall is greater than said diameter of said piston means, thereby, when said piston means is in said forward portion of said case, providing an annular gap between said piston means and said side wall.

37. A weapon system according to claim **34** wherein:

said container means is a cartridge case, and including:

resilient stop means disposed in said cartridge case for resiliently limiting aftward movement of said piston in said cartridge case.

38. A weapon system according to claim **34** wherein:

said container means is a cartridge case, and

the internal diameter of the aft portion of said side wall of said cartridge case is equal to the diameter of said piston means, and

the forward portion of said cartridge case includes a plurality of annular compartments, each inwardly open and defining a central bore through which said piston means passes.

39. A weapon system according to claim **38** further including:

a quantity of liquid propellant disposed within said annular compartments.

* * * * *

United States Patent [19]

Ashley

[11] **4,069,739**

[45] **Jan. 24, 1978**

[54] **LIQUID PROPELLANT WEAPON SYSTEMS**

[75] Inventor: **Eugene Ashley,** Burlington, Vt.

[73] Assignee: **General Electric Company,** Burlington, Vt.

[21] Appl. No.: **707,143**

[22] Filed: **July 20, 1976**

Related U.S. Application Data

[62] Division of Ser. No. 469,507, May 13, 1974, abandoned.

[51] **Int. Cl.**[2] **F41F 15/00;** F41F 1/04

[52] **U.S. Cl.** **89/1.704;** 89/7

[58] **Field of Search** 89/1.703, 1.704, 1.705, 89/1.706, 1.7, 7, 8; 102/38

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Primary Examiner—David H. Brown
Attorney, Agent, or Firm—Bailin L. Kuch

[57] **ABSTRACT**

A gun and ammunition system utilizing a round of ammunition which contains a supply of liquid propellant and after ignition pumps this propellant into the combustion chamber of the gun.

1 Claim, 21 Drawing Figures

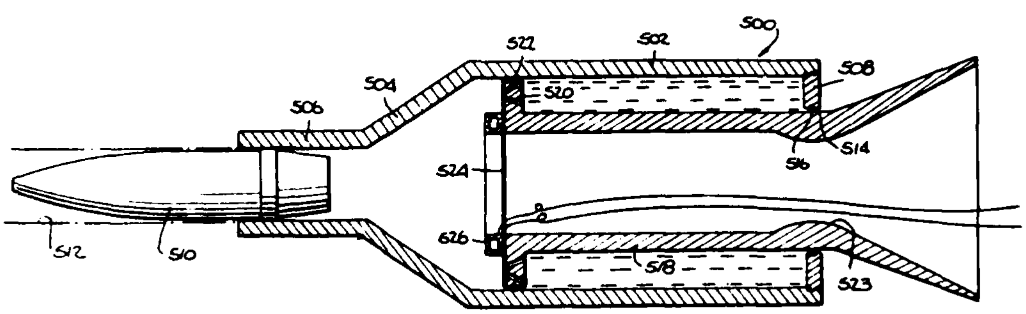


Fig. 1.

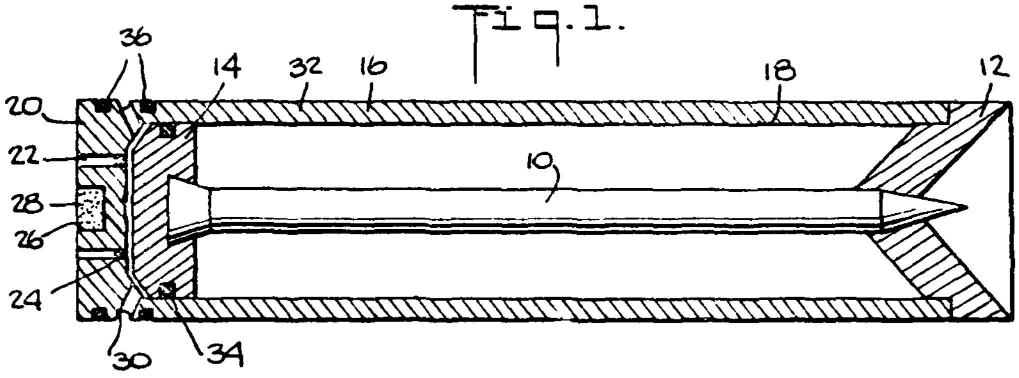


Fig. 3.

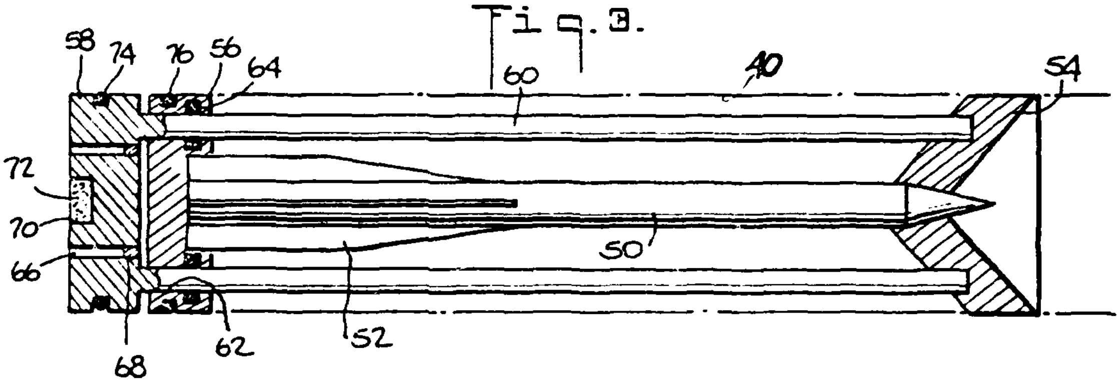
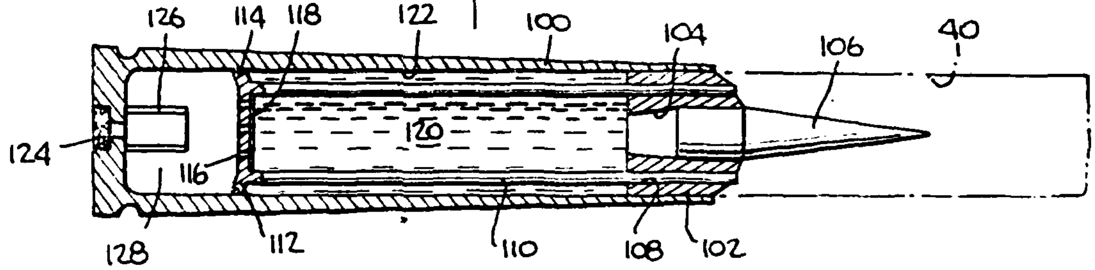


Fig. 4.



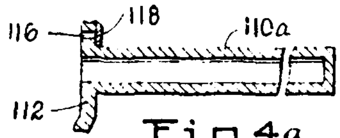


Fig. 4a

Fig. 5.

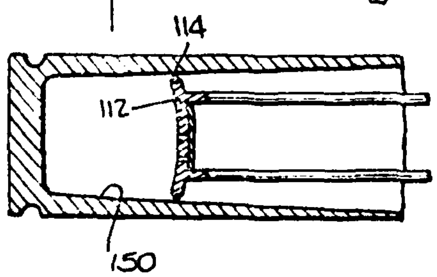
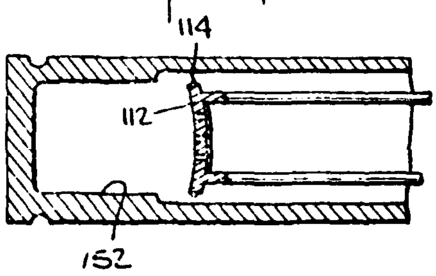


Fig. 6.



LOADING POSITION

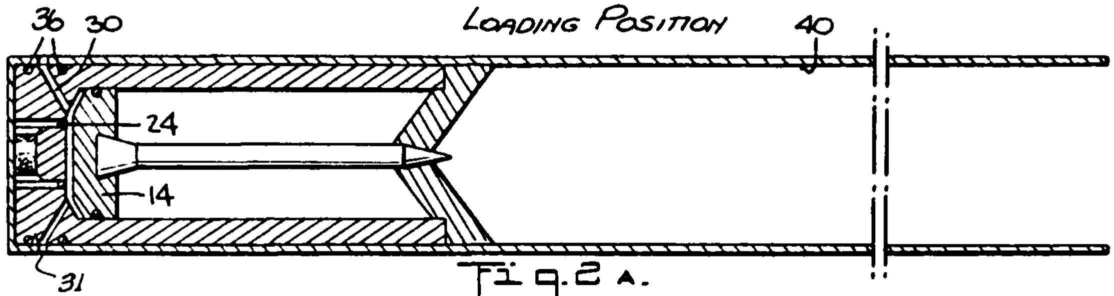


Fig. 2A.

FIRING POSITION

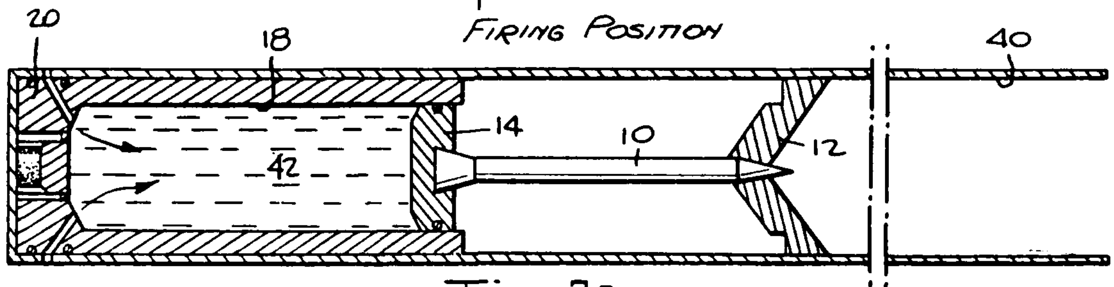


Fig. 2B.

INITIATION

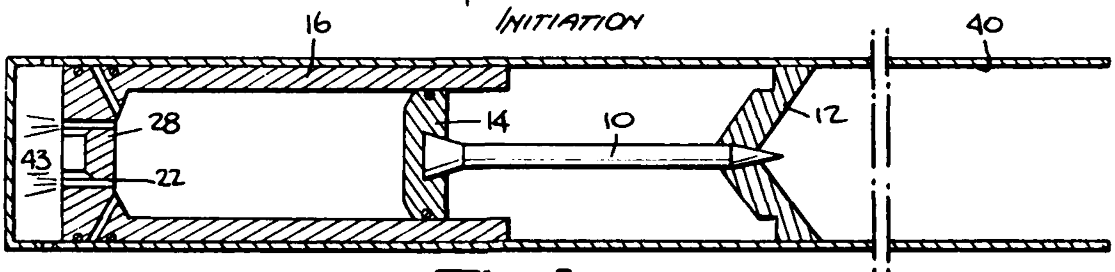


Fig. 2C.

MID-BORE POSITION

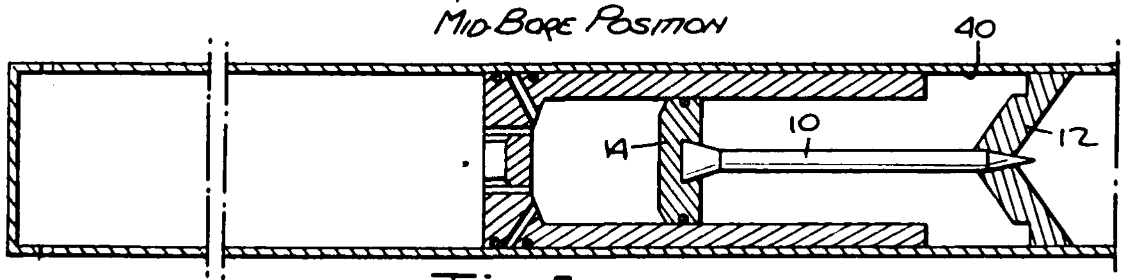


Fig. 2D.

SABOT STRIPPING

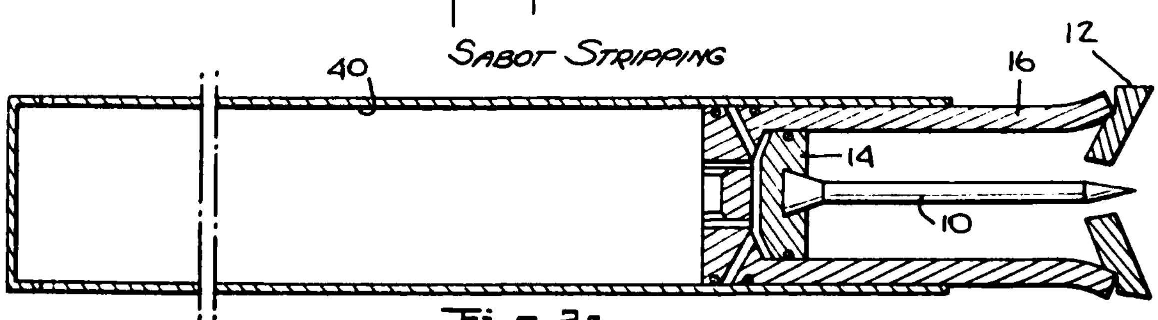


Fig. 2E.

Fig. 8.

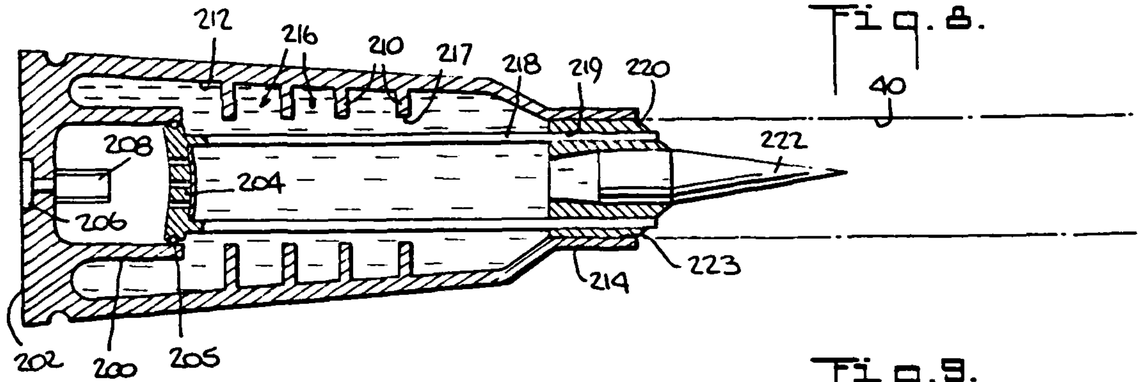


Fig. 9.

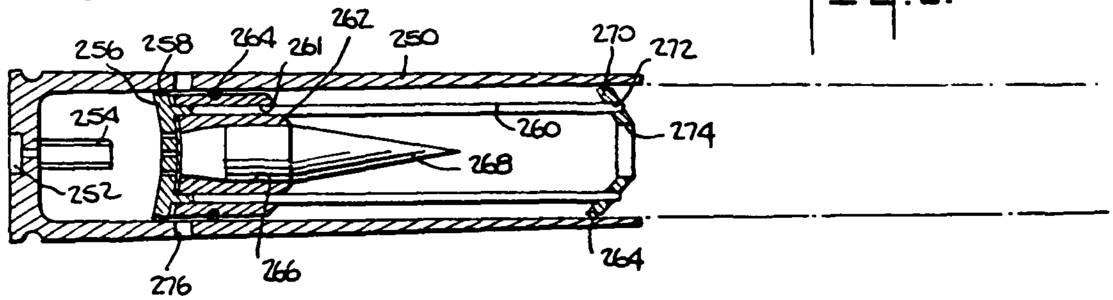


Fig. 10.

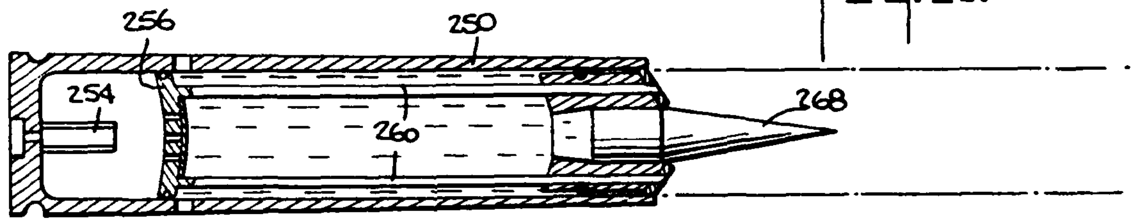
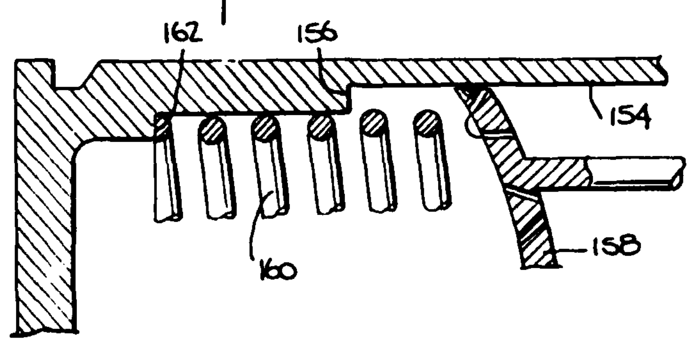


Fig. 7.



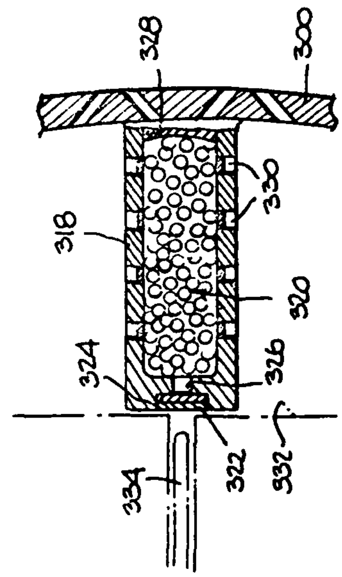


Fig.13.

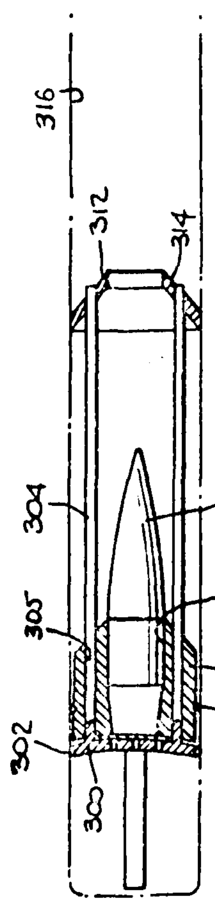


Fig.11.

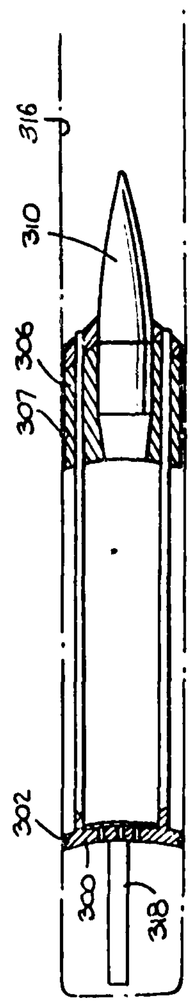


Fig.12.

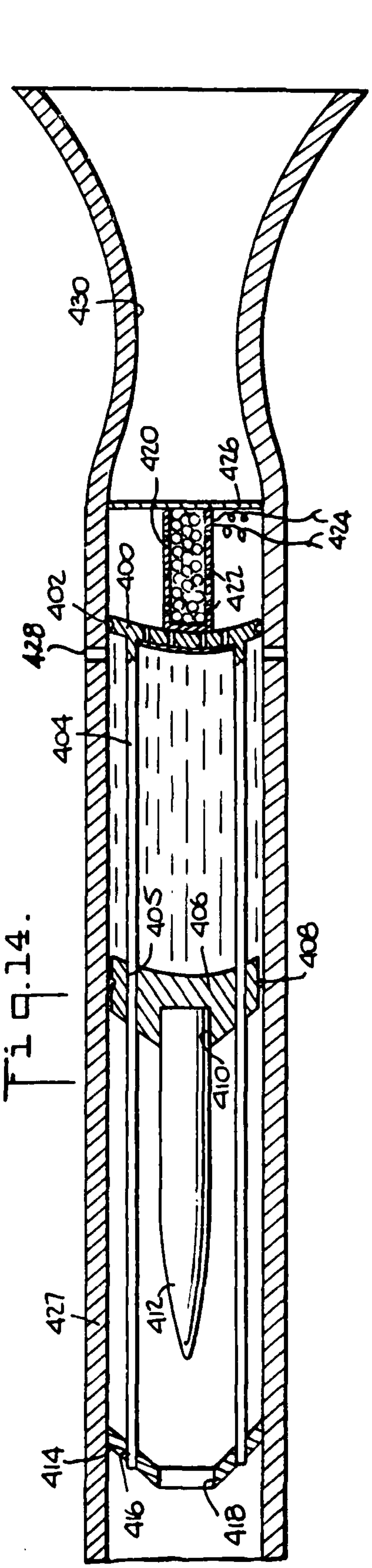


Fig.14.

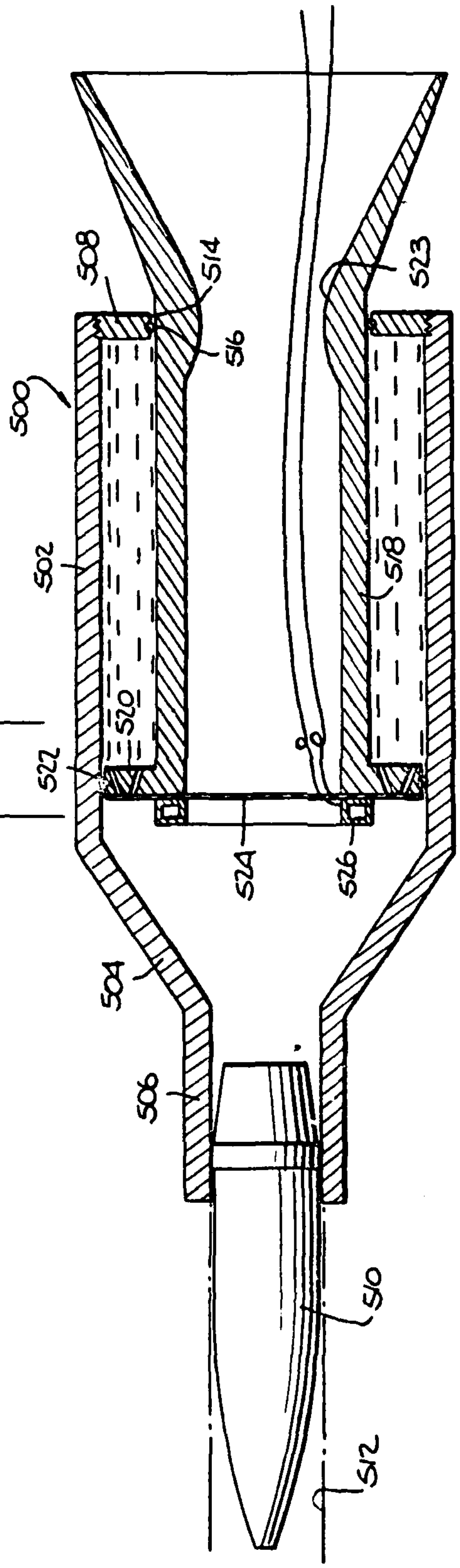

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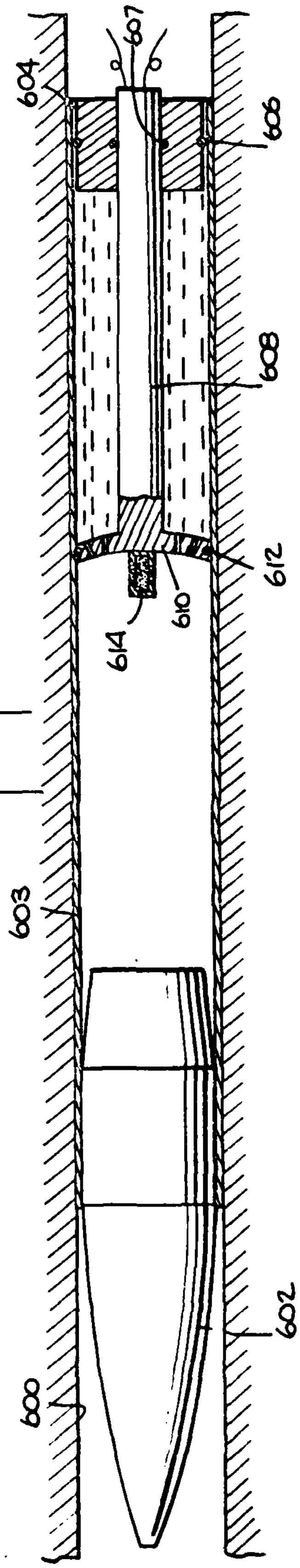
Fig. 15.


600
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608
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612
614

Fig. 16.

UNITED STATES PATENT OFFICE

CERTIFICATE OF CORRECTION

Patent No. 4,069,739 Dated January 24, 1978

Inventor(s) Eugene Ashley

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

Title, change "Systems" to --System--.
Column 3, line 43 change "bore" to --bores--.

Signed and Sealed this

Seventh **Day of** *November 1978*

[SEAL]

Attest:

RUTH C. MASON
Attesting Officer

DONALD W. BANNER
Commissioner of Patents and Trademarks

LIQUID PROPELLANT WEAPON SYSTEMS

This application is a division of Ser. No. 469,507, filed May 13, 1974, now abandoned.

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates to weapon systems employing a liquid propellant, and particularly to such systems wherein the propellant is continuously pumped into the combustion chamber as the projectile advances along the firing bore.

2. Prior Art

Weapons systems providing traveling charge effects on projectiles, or rockets, or other related systems, are shown, for example, in U.S. Pat. Nos. 3,431,816; 3,411,403; 3,459,101; 3,496,827; 3,601,056; 3,613,499; 3,628,457; 3,648,616; 3 565,803; 3,696,749; 3,698,321; 3,712,171; and 3,728,937. In a final report for the Bureau of Ordnance, Department of the Navy, under Contract NOrd 16217 Task 1, dated Sept. 1, 1957, work was described on a propellant carrying projectile. "This projectile contained approximately 100 grams of a hydrazine, hydrazine nitrate, water monopropellant (63, 32, and 5% by weight respectively). Upon ignition of the primary bipropellant charge in the breech, regenerative injection of the bipropellants progresses in the usual manner, and the projectile is accelerated. The accelerating forces upon the projectile components are so adjusted as to produce relative motion between the projectile body and the center plunger. This motion expels the extrapped monopropellant rearward past the fragile seal disk into the hot combustion chamber gases, where it burns while the projectile is accelerated." The projectile apparently comprised a forward solid cylindrical projectile whose outer wall engaged the inner wall of the firing bore, an intermediate, longitudinally central rod journaled through a bore in the projectile, and an aft sealing disk fixed to the rod and whose periphery engaged the inner wall of the firing bore. The monopropellant was trapped between the forward cylindrical projectile and the aft disk within the firing bore. Solid primary charges were also used in lieu of liquid primary charges. A separate static sealing disk was also used in lieu of the peripheral seal on the aft sealing disk.

SUMMARY OF THE INVENTION

It is an object of this invention to provie a gun and ammunition system for launching rod-shaped projectiles at high velocity.

It is an additional object to provide such a system utilizing liquid propellants.

A feature of this invention is the provision of a gun and ammunition system utilizing a round of ammunition which contains a supply of liquid propellant and after ignition pumps this propellant into the combustion chamber of the gun.

An additional feature of this invention is the provision of a gun and ammunition system utilizing a round of ammunition carrying a relatively narrow diameter and relatively high mass projectile in a relatively wide and relatively low mass sabot, which is initially accelerated by a primary propellant charge in the combustion chamber aft of the projectile and which is subsequently accelerated by a secondary propellant charge in the round which is passed during a relatively extended period of time to the combustion chamber.

BRIEF DESCRIPTION OF THE DRAWING

These and other objects, features and advantages of this invention will be apparent from the following specification thereof taken in conjunction with the accompanying drawing in which:

FIG. **1** is a view in longitudinal cross-section of an idealized round of ammunition having a sabot and a system to regeneratively pump liquid propellant, the round is here shown in its telescoped, minimum length configuration, without liquid propellant;

FIGS. **2A** through E respectively illustrate, within the gun bore, the

A. before charging with liquid propellant configuration,

B. after charging with liquid propellant and ready for initiation of the primer configuration,

C. shortly after initiation and commencement of injection of liquid propellant into the combustion chamber configuration,

D. midbore configuration, and

E. bore exiting and sabot stripping configuration,

in the sequence of operations of the round of FIG. **1**.

FIG. **3** is a view in longitudinal cross-section of a second embodiment of this invention;

FIG. **4** is a view in longitudinal cross-section of a third embodiment of this invention;

FIG. **4*a*** is a detail of a variant of the embodiment shown in FIG. **4**;

FIGS. **5** and **6** are views in longitudinal cross-section of a fourth embodiment of this invention;

FIG. **7** is a view in longitudinal cross-section of a fifth embodiment of this invention;

FIG. **8** is a view in longitudinal cross-section of a sixth embodiment of this invention;

FIGS. **9** and **10** are views in longitudinal cross-section of a seventh embodiment of this invention;

FIGS. **11**, **12** and **13** are views in longitudinal cross-section of an eighth embodiment of this invention;

FIG. **14** is a view in longitudinal cross-section of a ninth embodiment of this invention;

FIG. **15** is a view in longitudinal cross-section of a tenth embodiment of this invention; and

FIG. **16** is a view in longitudinal cross-section of an eleventh embodiment of this invention.

DESCRIPTION OF THE EMBODIMENTS

Rod shaped penetrators launched at high velocities from medium caliber guns are effective against some types of armor. Since rod penetrators are characteristically long and thin, sabot launching techniques are conventionally employed. The sabot in this case is essentially a light weight piston of diameter larger than the penetrator, and which supports the heavier penetrator. In the launching or firing process, the combustion gas acts against the area of the full diameter of the sabot, rather than against the rod alone, in accelerating the two in combination.

Liquid propellants have several desirable characteristics, such as relatively low flame temperature and ease of storage and handling. A major problem in the use of liquid propellants lies in the control of the ballistic process in the combustion chamber. Propellant can be either placed in the chamber before firing and then be ignited; or it can be metered into the chamber during the combustion process. The last mentioned, sometimes

called preloading, is easier to do mechanically, but permits little control over burning after ignition. U.S. Pat. No. 3,763,739 issued to D. P. Tassie on Oct. 9, 1973, discloses a gun system of this type. The second mentioned, sometimes called forced injection, permits control over the rate of burning through control over the rate of introduction of the propellant, but involves extremely high pumping pressures. Such high pressures pose stringent requirements on seals, fittings and structural components. If the energy for forced injection is to be supplied from an external source, the power requirements are very high. For example, the power required to pump three cubic inches of propellant across a pressure drop of 10,000 psi in 20 milliseconds is 227 hp. This can be averaged over a larger period in an actual gun to lower the peak value, but the power requirement is still unreasonable.

An effective solution to the power requirement for pumped injection is to utilize the combustion chamber pressure itself as the source of energy for pumping. Called regenerative injection, this scheme uses a differential area piston for each propellant. The larger end of the piston is acted on by the chamber pressure, and the smaller end pressurizes the propellant to be injected. The difference in areas generates a propellant pressure sufficiently higher than the chamber pressure to achieve the desired rate of injection.

FIRST EMBODIMENT

Turning now to FIG. 1, a first embodiment of the invention is shown as an idealized round of ammunition having a sabot and regenerative, liquid propellant pumping system, for use in a gun which will fill the round with propellant before firing. The penetrator **10** is here shown as a rod which upon launching will be drag stabilized. The sabot is a three piece assembly, comprising an annular nose stabilizer **12** fixed to the forward end of the penetrator, a circular pusher-plate **14** fixed to the aft end of the penetrator, and a cylindrical body **16**. The body **16** has an internal bore **18** closed at its aft end **20**, which bore receives the plate **14**. The aft end **20** serves as an injector plate and has a plurality of longitudinal bore **22** therethrough serving as injection passageways. Each bore is obturated by a respective plug **24**. An aft recess **26** receives a primary propellant charge, here shown as a solid primer **28**. One or more substantially radially oriented bores **30** pass through the side wall **32** of the body into the interface between the plate **20** and the plate **14**, to serve as propellant fill passageways. An annular seal **34** is provided on the periphery of the plate **14**, and a pair of annular seals **36** are provided on the periphery of the body **16** straddling the fill passageways.

The plugs **24** may be embodied as relief valves, individual plugs, a burst diaphragm fixed to the forward face of the injector plate, or simply portions of the bore material not fully drilled through, all of which will shear or open at the desired pressure level.

The penetrator and sabot assembly may be preloaded with liquid propellant through the fill passageways, which are then plugged, before being placed in the gun. Alternatively, the assembly may be placed in the firing bore **40** of the gun and then loaded with propellant. The actual firing process is the same for each scheme, and loading within the gun will be discussed with respect to FIGS. 2A through 2C.

As shown in FIG. 2A, the penetrator and sabot assembly, still without its propellant charge, has been placed into the breech of a gun barrel and the breech has been closed. The fill passageways **30** are aligned with suitable fill ports **31** in the breech wall of the gun, such as are shown in U.S. Pat. No. 3,763,739, supra, which must incorporate high pressure fill valves or check valves which can withstand firing pressure. These passageways serve as means for providing liquid propellant to the round of ammunition in the firing bore.

As shown in *FIG. 2B*, propellant is pumped into the interface between the injector plate **20** and the pusher plate **14**, progressively pushing the pusher plate forward within the bore **18** to create an injection volume **42** which receives a complete charge. Stops can be provided to halt the forward advance of the nose stabilizer, or preferably, the charge can be metered. The round is shown fully charged and ready for firing.

As shown in FIG. 2C, firing is initiated by setting off the primer, which rapidly generates a small volume of high pressure, hot gas in the space **43** aft of the injector plate which serves as the combustion chamber. This high pressure aft of the loaded round produces an immediate acceleration of the complete round. The overall force producing the acceleration, which force is equal to the chamber pressure times the chamber cross-sectional area, is exerted against the aft face of the injector plate. The penetrator and sabot assembly has a relatively high weight relative to the weight of the body **16** with a correspondingly relatively high inertia. A portion of the accelerating force is absorbed in accelerating the body **16** per se, but the remainder of the accelerating force is transmitted by the forward surface of the injector plate against the charge of liquid propellant. The resultant pressure developed in the liquid is the transmitted force divided by the liquid or injection volume cross-sectional area. When the ratio of the areas of the aft face of injector plate and the injection volume, and the body weight and the total round weights are properly predetermined, a liquid pressure will be generated which is higher than the chamber pressure as follows:

$$\frac{P_L}{P_C} = \frac{A_C}{A_L}\left(1 - \frac{W_B}{W_{TOT}}\right)$$

where

P_L is liquid pressure,
P_C is chamber pressure,
A_C is chamber area,
A_L is liquid area,
W_B is body weight, and
W_{TOT} is the sum of the body, the liquid and the penetrator and sabot assembly weights.

The difference between the two pressures P_L and P_C is the driving force which can be utilized for regenerative injection.

The plugs **24** are designed to open at a predetermined difference in pressure between the interior volume and the combustion chamber. These plugs serve as a pressure sensitive obturating means. As shown in FIG. 2C, when this difference is reached, the plugs will open and propellant will flow into the chamber. The injection passageways **22** serve to atomize or break up the propellant streams through techniques similar to those used in rocket injector design. As the propellant streams initially encounter the hot primer gases they ignite, generating more hot gas. Incoming propellant continues to ignite and the process becomes self sustaining, and gen-

erates increasing chamber pressure, which accelerates the process. The process continues until the propellant is expended. Meanwhile, the whole round is being accelerated along the bore by what is in effect, a traveling charge. FIG. 2D shows the round at mid-bore length with the propellant partially expended.

As the round leaves the muzzle, the sabot fore and aft supports are stripped from the penetrator which continues on its course. FIG. 2E shows the nose stabilizer **12** acting under wind forces to open the body **16** and free the penetrator.

The entire body **16** is here shown as engaging the rifling of the bore **40** to provide spin to the entire round if a spin stabilized projectile is used. Alternatively a lesser annular portion of the body may engage the rifling.

SECOND EMBODIMENT

Frictional forces are developed between the body **16** and the interior wall of the bore **40** as the round is launched, which are a function of the materials of the body 16 and the bore **40** of the gun barrel. An alternative embodiment which minimizes such frictional forces is shown in FIG. 3.

The penetrator **50** is here shown as a rod which is stabilized by a plurality of fins **52**. The sabot is a three piece assembly comprising an annular nose stabilizer **54** fixed to the forward end of the penetrator, a circular pusher-plate **56** fixed to the aft end and an injection plate **58** having a plurality of forwardly, longitudinally extending, integral rods **60**. The pusher plate **56** has a like plurality of longitudinal bores **62** with respective annular seals **64** each passing a respective one of the rods **60**. The injector plate **58** also has a plurality of longitudinal bores **66** therethrough each obstructed by a respective plug **68**, and an aft recess **70** receiving a primary propellant charge **72**, all similar to the embodiment of FIG. **1**. These plugs **68** serve as a pressure sensitive obturating means. An annular seal **74** is provided in the periphery of the injector plate, and an annular seal **76** is provided in the periphery of the pusher plate. This penetrator and sab. assembly is disposed in the gun for filling with propellant with the fill ports in the breech wall of the gun aligned with the interface between the injection plate and the pusher plate.

The use of the rods **60** upon which the pusher plate can slide permits the omission of the body structure, so that only the peripheries of the pusher plate, the injector plate and the stabilizer need contact the wall of the barrel bore **40**. The liquid propellant is contained between the pusher plate, the injector plate and the wall of the barrel bore. The necessary differential in areas is provided by the total cross-sectional areas of the rods. **60**. The rods provide an added advantage in the sabot stripping phase of the launching cycle as they are relatively weaker and therefore easier to deflect radially outwardly than the equivalent cylindrical body **16**.

Both of the embodiments described above provide the following advantages:

1. Controlled injection is achieved through regenerative pumping action;
2. The inertia of the projectile itself is the source of the pumping force;
3. The injection mechanism is incorporated into the penetrator and sabot assembly, with very little effect on the gun design;
4. A traveling charge effect is achieved;
5. The injection system and high pressure seals are used only once for each shot and are then discarded.
6. The sabot and projectile assemblies may be stored and transported as essentially inert, considering the primer to be relatively insignificant. The assemblies do not become active until the introduction of the propellant. This can be delayed until after chambering and locking in the gun.

The specification so far has dealt with idealized projectile and sabot assemblies and their launching techniques. Cartridges embodying such assemblies may be provided in at least several different configurations.

THIRD EMBODIMENT

FIG. **4** shows the simplest pre-filled cartridge case embodiment. The projectile and sabot assembly are crimped into a cartridge case **100**. The assembly comprises a forward annulus **102** which serves as a pusher plate and has a central bore **104** receiving a spin stabilized projectile **106** and a plurality of bores **108** disposed in an annular row, each receiving a respective one of a like plurality of rods **110** which are respectively fixed to an injector plate **112**. The injector plate has an annular seal **114** fixed to its periphery and a plurality of longitudinal injection passageways **116** which are closed by a diaphragm **118** fixed to the forward face of the plate. The liquid propellant charge **120** is contained between the annulus **102**, the plate **112** and the inner wall **122** of the case **100**. The bore of the case includes an external primer **124** in communication with an internal booster tube **126** disposed in the combustion chamber **128** which is defined by the base of the case, the injector plate and the interior wall of the case. Upon ignition the injector plate and its rods move forwardly relative to the annulus, rupturing the diaphragm and injecting propellant into the combustion chamber. This diaphragm serves as a pressure sensitive obturating means. The inner wall **122** of the case is cylindrical and coplanar with the inner wall **40** of the bore of the gun barrel, so that the forward annulus and the injector plate smoothly leave the case and ride along the gun bore. The forward annulus may be made up of segments to provide ready rupture and release of the projectile when the assembly leaves the gun bore.

The injector plate **112** may be made of arched cross-section for a greater strength to weight ratio.

The rods **110** may be replaced with hollow tubes **110a**, as shown in FIG. **4a**; which are closed at their forward ends and open at their aft ends so that the interior volume of each tube communicates with and is at the same pressure as the combustion chamber **128**. This permits the use of a thin wall tube whose wall thickness becomes progressively thinner from front to rear; since as the length of the tube exposed forwardly of the annulus **102** into the atmosphere increases, the combustion chamber pressure decreases.

FOURTH EMBODIMENT

In the embodiments discussed above, all of the injection of the propellant into the combustion chamber takes place through the passageways of the injector plate. An enlarged "Taylor cavity" will be formed by providing a tubular cylinder of propellant liquid in the combuston chamber as said chamber is being enlarged by the forward movement of the injector plate. The "Taylor cavity" provides a liquid-gas interface for combustion. This is accomplished by providing a variable

internal diameter in the case which increases towards the mouth of the case. As shown in FIG. 5, the bore **150** of the case may be tapered, or as shown in FIG. 6, the bore **152** of the case may be stepped to provide a variable, increasing, orifice for the liquid propellant around the periphery of the injector plate.

FIFTH EMBODIMENT

The injector plate should be prevented from moving aft under impulse load exerted by the liquid propellant under conditions of vigorous handling or in the event a cartridge is dropped on its base. This can be accomplished by providing stops on the displacement rods aft of their engagement with the injector plate; a step can be provided in the interor wall of the case aft of the injector plate; or the injector plate may be fastened to the interior wall of the case by a weak joint which will rupture under the firing forces. To further minimize the effects of handling loads the stops may be made resilient. As shown in FIG. 7, the interior wall **154** may be provided with a step **156** to abut the outer margin of the injector plate **158**. A helical spring **160** may be captured between an additional step **162** and the injector plate to resiliently fix the inputs plate and to permit it to move aft slightly before abuting the positive shoulder **156**.

SIXTH EMBODIMENT

In the embodiment shown in FIG. 8, a prefilled case is provided which has an interior annular wall **200** extending from the base **202** which together with the injector plate **204** and its peripheral seal **205** defines an initial combustion chamber. An external primer **206** communicates with an internal booster **208** disposed in the initial combustion chamber. A plurality of rigid, spaced apart, partitions **210** extend inwardly from the interior wall **212** of case which is tapered progressively inwardly from the base to the neck **214** to provide a series of compartments **216** of decreasing volume, each opening into a central bore **217**. As described with respect to FIG. 4, the injector plate is fixed to rods **218** which are journaled through respective bores **219** in an annulus **220** which retains the projectile **222**. The bore **223** of the neck is coplanar with the gun bore **40**. Liquid propellant is stored forward of the injection plate in the compartments **216** and in the central bore. The propellant in the central bore is injected into the combustion chamber by the injection plate as discussed with respect to FIG. 4. The propellant in each open compartment **216** tends to remain in place and to ignite as its compartment is exposed to the initial combustion chamber as the injection plate moves forward, also providing a "Taylor Cavity" effect.

SEVENTH EMBODIMENT

FIGS. 9 and 10 show a dry loaded cased cartridge embodiment, similar to the case of FIG. 4. The cartridge is provided with a case **250** having a primer **252** communicating with a booster charge **254**, and a projectile and sabot assembly. The sabot includes an injector plate **256** having a peripheral seal **258** and a plurality of longitudinally extending rods **260** fixed thereto and respectively journaled through bores **261** in an annulus **262** which has a peripheral seal **264** and an axial bore **266** receiving a projectile **268**. A stabilizing ring **270** is retained against non-firing loads aft of the mouth of the case as by cementing or crimping and has a like plurality of bores **272** journaling said rods **260** and an axial bore **274** adapted to pass the projectile. A plurality of radial bores **276** are disposed through the case in an annular row to serve as propellant filling passageways. In the stored configuration, as shown in FIG. 9, the annulus **262** is nested aft, close to the injector plate, without any liquid propellant, and the seals **258** and **264** straddling the row of bores **276**. After the case has been loaded into the gun and the gun breech has been locked, the liquid propellant charge is pumped through aligned ports in wall of the breech of the gun as described with respect to FIG. 2B. The injector plate is prevented from aftward movement by suitable means, such as the stops described with respect to FIG. 7. As the liquid propellant charge is pumped into the interface between the injector plate and the annulus, it forces the annulus forward until it is stopped by the stabilizing ring, which provides an automatic metering device for the filling operation.

Both pre-loaded and dry-loaded cased cartridges share the following advantages:

1. Sealing of the breech is provided by the case.
2. The priming system is conveniently provided for each round.
3. A misfired round can be completely extracted by extracting the case.

The dry-loaded cartridge has the additional following advantages for shipping and handling:

1. The projectile is telescoped within the case for shipping and for loading into the gun. This minimizes the length of the parts to be handled.
2. The cartridge is relatively safe. In the absence of propellant, the primer and booster are the only combustible components present.
3. The propellant is loaded separately through control valves and piping. This can be controlled remotely if necessary.
4. The breech is closed before the propellant is charged into the cartridge, providing additional safety.

EIGHTH EMBODIMENT

FIGS. 11 and 12 show a dry loaded uncased cartridge, which is loaded, locked, filled and fired in a manner similar to the cased cartridge of FIGS. 9 and 10. The sabot and projectile assembly comprises an injector plate **300** having a peripheral seal **302** and a plurality of longitudinally extending rods **304** fixed thereto and respectively journaled through bores **305** in an annulus **306** which has a peripheral seal **307** and an axial bore **308** receiving a projectile **310**. A stabilizing ring **312** has a like plurality of bores **314** journaling said rods **304** and an axial bore **316** adapted to pass the projectile. As show[illegible]G. 13, a primer and booster assembly compri[illegible] **318** which cemented to the aft face of the injec[illegible] The sleeve is molded of solid propellant, o[illegible] strength to provide a small combustion chamber **320** initially, but which will ultimately burn. A combustible primer **322** is fixed in a cup **324** in the exterior of the base of the sleeve and which communicates by a passageway **326** with the combustion chamber **320**. The forward end of the sleeve is closed with a plug **328** which may be cemented. Radially extending flame passageways **330** are provided through the walls of the sleeve. These passageways are initially closed, as by plugs, being only partially formed through, or covered by a diaphragm. Loose powder is disposed in the combustion chamber.

The length of the primer and booster assembly is made equal to the length of the combustion chamber of the gun. When the cartridge is chambered and the

breech is locked, the primer **322** is adjacent the face **332** of the breech block, and may be ignited by a conventional percussion firing pin **334**, or electrical firing means. The primer ignites the loose powder immediately, generating hot gases which rupture the flame passageway closures and pass into the combustion chamber. The molded combustible sleeve burns more slowly than the loose powder, but eventually all is consumed. The hot gas initiates the regenerative liquid propellant injection process as described previously.

The dry-loaded caseless cartridges have the following advantages:

1. The system is completely combustible. The gun chamber is completely empty after each shot.
2. The primary system is an integral part of the cartridge as supplied to the gun.
3. The primary system may be fabricated using conventional caseless ammunition technology.

NINTH EMBODIMENT

FIG. **14** shows a recoiless gun embodiment of a caseless cartridge similar to that shown at FIG. **12**. The sabot and projectile assembly comprises an injector plate **400** having a peripheral seal **402** and a plurality of longitudinally extending rods **404** fixed thereto and respectively journaled through bores **405** in an annulus **406** which has a peripheral seal **408** and an axial bore **410** receiving a projectile **412**. A stabilizing ring **414** has a like plurality of bores **416** journaling said rods **404** and an axial bore **418** adapted to pass the projectile. A priming system comprising a sleeve **420** which may be molded of solid propellant is cemented to the aft face of the injector plate **400**. The sleeve has radially extending flame passageways **422** which are initially closed and contains loose powder which may be ignited by an electrical firing system **424**. A frangible diaphragm **426** is cemented to the aft end of the sleeve. The initial combustion chamber is provided within the sleeve, and the subsequent combustion chamber is defined between the injection plate and the diaphragm. The diaphragm is adapted to burst at a pressure which is high enough to insure that initiating combustion has been achieved.

The gun **427** includes suitable ports **428** to pass liquid propellant to the interface between the injection plate **400** and the annulus **406**. The gun also includes a converging/diverging nozzle **430** in lieu of the conventional closed breech. This nozzle may be of the type shown, for example, in U.S. Pat. Nos. 2,444,949, 2,696,760, 2,790,353 and 3,610,093. The nozzle provides an expansion chamber and a venturi orifice therein to allow a sufficient amount of the combustion gases to expand and escape rearwardly, thereby stabilizing the gun against recoil. The nozzle may be made separable from the breech to permit loading of the cartridge. FIG. **14** shows the annulus **406** midway in its forward advance during the loading with liquid propellant.

TENTH EMBODIMENT

FIG. **15** shows a recoiless gun embodiment of a cased, preloaded cartridge. The cartridge includes a case **500** having a side **502**, a shoulder **504**, a neck **506** and a base plate **508** threaded into the side **502**. A projectile **510** is crimped into the neck, and is received in the firing bore **512** of the gun. The base plate **508** has central bore **514** with an annular seal **516** to pass the neck **518** of a tubular injector and nozzle assembly. This assembly includes an annular injection plate **520** having an annular seal **522** integral with the forward end of the neck and a converging/diverging nozzle **523** integral with the aft end of the neck. A frangible diaphragm **524** is cemented over the forward end of the tube and an annular priming system **526** is cemented onto the diaphragm. The priming system is similar to a torus of square cross-section, having flame passageways, loose powder, and an electrical firing system whose leads may be brought through the diaphragm and out the bore of the neck and the nozzle or through the sidewall of the case. Liquid propellant is stored in the chamber defined by the base plate **508**, the injection plate **520**, the side **502**, and the neck **518**.

This embodiment does not provide a traveling charge. Ignition of the priming system ruptures the diaphragm and moves the injector and nozzle assembly aft, which in turn provides regenerative pumping forwardly of the liquid propellant through the passageways of the injector plate.

ELEVENTH EMBODIMENT

FIG. **16** shows a recoiless gun embodiment of a cased cartridge employing a reaction or compensating mass of the type shown in U.S. Pat. No. 1,108,716. This embodiment does not provide a traveling charge. In its simplest form, the gun includes a firing bore **600** open at both ends. A projectile **602** and an injector and reaction mass assembly are secured in a tubular cartridge case **603** which is disposed in the bore **600**. The assembly comprises a solid reaction mass **604** having a peripheral seal **606** and a central bore with an annular seal **607**, in which is journaled a rod **608** to whose forward end is fixed in injection plate **610** having a peripheral seal **612**. A priming system **614** is fixed to the forward face of the injection plate. The priming system may comprise a sleeve molded of combustible material with flame passageways, filled with loose powder, and having an electrical firing means which may be brought out through the rod **608**. Firing is initiated by hot gases generated by the priming system in the combustion chamber defined between the projectile and the ignition plate. The liquid propellant is stored in the chamber defined between the injection plate and the reaction mass, and serves as part of the total reaction mass, so that the solid mass actually ejected out the breech of the gun is less than required by fixed, solid propellants. In a caseless embodiment, not shown, the case is omitted and the liquid propellant is injected as discussed with respect to FIG. **2B**.

It is contemplated that the inventive concepts hereinabove described may be variously otherwise embodied and combined without departing from the inventive principles included and intended to be covered by the appended claims, except insofar as limited by the prior art.

What is claimed is:

1. A weapon system comprising:

a gun having a firing bore;

a round of ammunition disposed in said firing bore including:

a longitudinally extending cartridge case having a forward end, and an aft end having a transverse base plate with a central bore;

a relatively high mass projectile means held in and closing said forward end of said cartridge case;

a relatively low mass piston longitudinally slidable within and sealed to the interior wall of said cartridge case and disposed aft of said projectile means and forward of said base plate;

said piston having a first face of relatively large cross-sectional area and a second face of relatively small cross-sectional area, a central bore longitudinally extending between said first and second faces, an additional passageway communicating said second face with said first face, and a pressure sensitive obturating means obturating said additional passageway and adapted to open said additional passageway upon a predetermined pressure being provided on said first face;

a converging/diverging nozzle fixed and sealed to said piston about said bore of said piston and journaled through and sealed to said bore of base plate; and

a burstable diaphragm fixed and sealed to said piston, obturating said bore of said piston;

said cartridge case, said projectile means and said first face of said piston and said diaphragm defining a combustion chamber;

said cartridge case, said base plate, said second face of said piston and said nozzle defining a liquid propellant storage chamber.

* * * * *

United States Patent [19]
Tassie et al.
[11] 4,085,653
[45] Apr. 25, 1978

[54] IGNITION DEVICE

[75] Inventors: Douglas Pray Tassie, St. George, Vt.; Robert A. Pustell, Andover, Mass.
[73] Assignee: General Electric Company, Burlington, Vt.

[21] Appl. No.: 723,367
[22] Filed: Sep. 15, 1976
[51] Int. Cl.² F41F 1/04
[52] U.S. Cl. .... 89/7; 174/102 P; 313/137
[58] Field of Search .... 174/102 P, 118, 77 R; 313/137; 102/28 R, 46; 89/7

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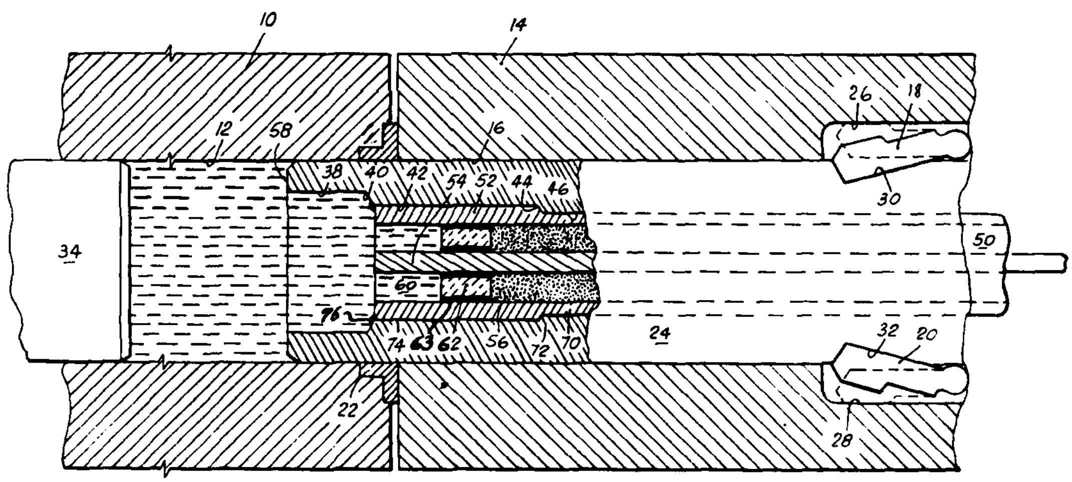
2,957,041	10/1960	Ziegler	174/77 R
3,121,038	2/1964	Perotte	174/118 X
3,608,492	9/1971	Mitchell	102/38
3,763,739	10/1973	Tassie	89/7
3,789,130	1/1974	Parker	174/118 X

Primary Examiner—David H. Brown
Attorney, Agent, or Firm—Bailin L. Kuch

[57] ABSTRACT

An igniter assembly for use in liquid propellant guns comprises an outer tubular conductor and an inner conductor spaced apart by a volume of tightly packed, irregular granules of an insulating material, such as a mineral powder. The outer conductor is supported in a longitudinal bore of a gun bolt.

10 Claims, 1 Drawing Figure



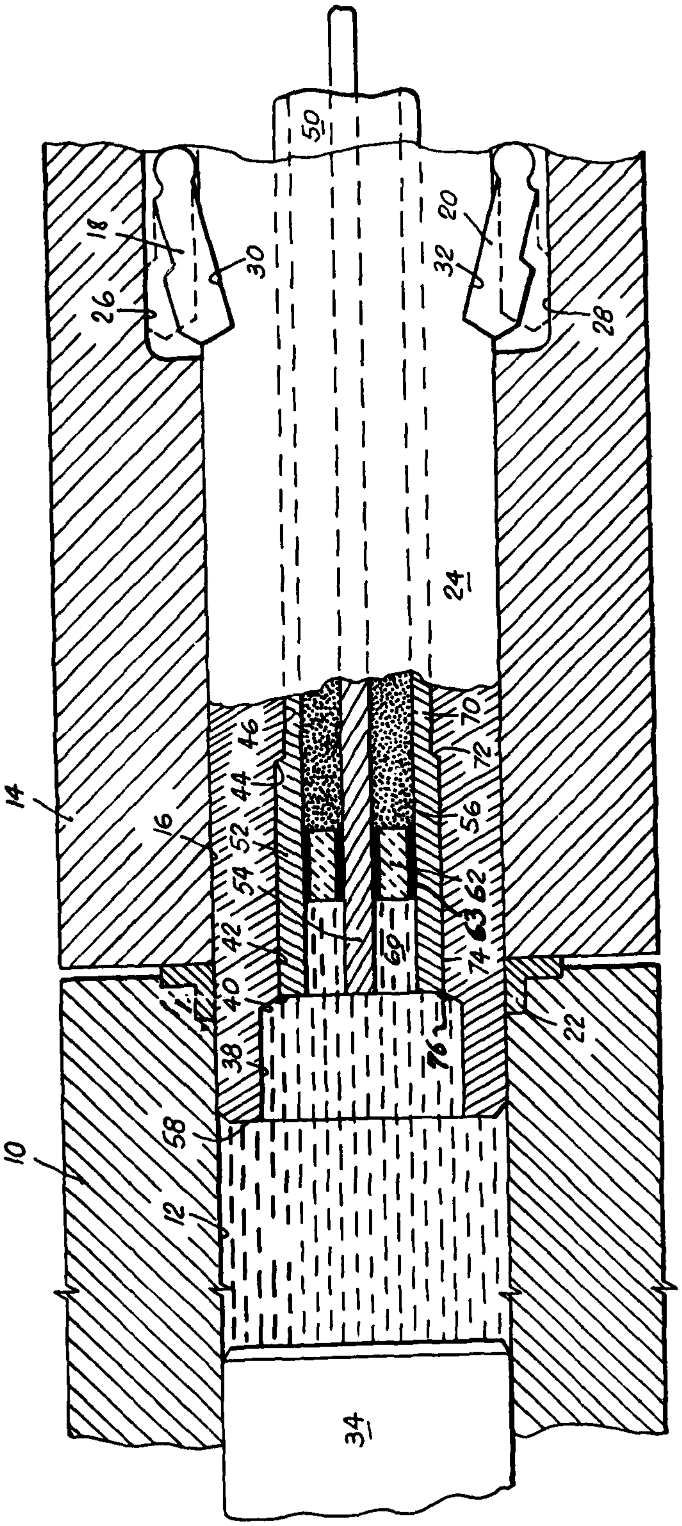

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FIG. 1.

IGNITION DEVICE

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates to ignition devices for use in a high mechanical shock environment, such as the ignition of liquid propellant in a gun, or the ignition of fuel in a jet engine.

2. Prior Art

The use of an igniter, per se, in a liquid propellant gun is shown by Broussard in U.S. Pat. Nos. 2,088,503, issued July 27, 1937; Rost in 2,129,875, issued Sept. 13, 1938; Barbieri et al. in 3,326,084, issued June 20, 1967; Myers in 3,673,917, issued July 4, 1972; Nelson et al. in 3,728,937, issued Apr. 24, 1973; Tassie in 3,763,739, issued Oct. 9, 1973; and Broxholm et al., 3,949,642 issued Apr. 13, 1976. Of these, Tassie and Broxholm et al. show the igniter coaxially mounted in the gun bolt, as does Mitchell in U.S. Pat. No. 3,608,492, issued Sept. 28, 1971 in a gun firing caseless ammunition.

The conventional igniter is an assembly of solid, rigid parts. The main insulator is usually a hard, high-fire ceramic, which is then combined with seals and fitted inside a strong, outer case which also serves as the outer conductor or electrode. The center electrode together with seals is fitted through a longitudinal bore in the main insulator. In a high mechanical shock environment, i.e., high pressure pounding, the assembly deteriorates: the seals deteriorate; the ceramic cracks, or one part slips with respect to another. Such slippage causes more breakage; the seal fails, combustion gas leaks, and eventually the igniter even fails to spark.

Accordingly, it is an object of this invention to provide an igniter which is unaffected by a high mechanical shock environment.

An additional object of this invention is to provide a gun bolt and igniter assembly which is effective in a liquid propellant gun.

Another object of this invention is to provide a process for the manufacture of such an igniter.

A feature of this invention is the provision of an igniter assembly comprising an outer tubular conductor and an inner conductor spaced apart by a volume of tightly packed, irregular granules of an insulating material, such as a mineral powder. The outer conductor is supported in a longitudinal bore of a gun bolt.

BRIEF DESCRIPTION OF THE DRAWING

These and other objects, advantages and features of the invention will be apparent from the following specification thereof taken in conjunction with the accompanying drawing in which:

FIG. 1 is a top plan view, in longitudinal cross-section through the gun bolt, of a liquid propellant gun utilizing an ignition device embodying this invention.

DESCRIPTION OF THE EMBODIMENT

A liquid propellant gun, for example, as is shown in the FIGURE, comprises a gun barrel **10** having a bore **12**, a breech **14** having a bore **16** and a pair of swinging lock blocks **18** and **20**, an annular seal **22** at the interface of the barrel and the breech, and a gun bolt **24**. The gun bolt reciprocates in the bore **16** and enters and obturates the bore **12**. The bolt is locked in its obturating station by the lock blocks **18** and **20** which may be swung between the recesses **26** and **28** in the breech and the recesses **30** and **32** in the bolt. A projectile **34** may be chambered in the bore **12** and a supply of liquid propellant may be inletted into the chamber between the projectile and the bolt. An exemplary system is shown in Tassie, U.S. Pat. No. 3,763,739.

The gun bolt has a longitudinal bore therethrough having a first portion **38**, a shoulder **40**, a second portion **42** of smaller diameter than said first portion, a shoulder **44**, and a third portion **46** of smaller diameter than said second portion.

An igniter **50** is fixed within the bore of the gun bolt. The igniter comprises an outer tube **52**, an inner rod **54**, a volume **56** of irregular tightly packed together particles spacing the rod concentrically within the tube, except proximal to the face **58** of the bolt, wherein a void **60** to serve as a spark chamber is provided between the tube **52** and the rod **54**. An annulus **62** may be fixed within the void to close the exposed end face of the volume of particles. In an exemplary igniter, the tube **52** is made of a relatively workable, conductive material such as **321** stainless steel, the rod **54** is made of **303** stainless steel wire, (both chosen for corrosion resistance) and the insulating material **56** is magnesium oxide powder (MgO). The annulus **62** is a hard fired ceramic bead. The seals **63** around the annulus **62** are made of a resilient material which is not soluble in the particular propellant or fuel which is to be ignited, e.g., fluorocarbon elastomer.

The igniter **50** is advantageously manufactured by compression techniques. In using a rotary swaging technique, the rod **54** is initially positioned within the empty tube **52**. The insulating powder **56** is poured into the tube and is either tamped or vibrated to a light degree of compaction. Alternatively, the rod **54** may be threaded into a number of crushable MgO beads, and this assembly slid into the empty tube **52**. The ends of the filled tube **52** are then closed, as by plugs or welding, to prevent the powder and wire from being forced out of the tube during subsequent compaction. The closed assembly of tube, rod and powder is fed into a set of rotating dies between hammers in a cage. As the dies rotate, they open and close on the tube to reduce its external diameter. The first pass collapses and eliminates all internal voids. Successive passes further reduce the diameter and increase the length of the assembly by the formula $V_1 = V_2$ where V_1 = volume before the pass and V_2 = volume after the pass, and $\pi R_1^2L_1 = \pi R_2^2L_2$. In essence, the tube and its internal parts are concurrently squeezed out from between the die. As an alternative to rotary swaging, drawing, rolling, press swaging, or plain hammering on an anvil die could be used.

After compaction, the aft portion **70** of the tube **52** is machined to reduce its external diameter and to produce a step or shoulder **72** which is congruent with the shoulder **44**, and the plugged ends are removed. The forward or pressure or chamber portion **74** of the tube **52** tightly fits into the bore portion **42** while the aft portion **70** loosely fits into the bore portion **46** and is brazed therein. The shoulders **72** and **44** are in tight abutment. The chamber end of the tube is welded at **76** (e.g., fusion process) to the shoulder **40** of the gun bolt.

The essential characteristic of the insulating powder is that it must be so tightly compressed by the outer tube **54** that there is no space left for any particle of that powder or for any part of any other element of the assembly to shift into under any pressure applied during use of the igniter. MgO was selected because it has good physical and dielectric properties at high temperature, and because its irregular particles interlock together

and into the adjacent metal surfaces under swaging better than any other material presently known. Other metal oxide mineral dielectric material may be used.

The void **60** is provided by air blasting out a quantity of particles from the chamber end of the igniter to expose a length of the exterior surface of the inner conductor and interior surface of the outer tube to act as electrodes.

This process of manufacture of collapsing the outer tube about the loose powder and the center conductor so tightly that everything is interlocked and cannot move irrespective of externally applied pressure, provides an assembly which behaves as if it were a solid rod of metal having the handling characteristics of the outer tube. Thus, pressure pulses beating on the forward face of the igniter cannot in any way disturb any of the parts of the igniter unless the outer tube expands, thereby loosening the powder. The gun bolt tightly fits around the igniter and supports it as a sheath both radially and longitudinally.

The annulus **62** does not fail under pressure pulses because it is firmly and evenly supported by the compacted powder **56** in the direction of the force, i.e., longitudinally, of the pulses. In all other directions the force of the pulses is simultaneously equal, and subjects the annulus only to a compressive stress which it can easily withstand.

The function of the annulus **62** and its seals is to prevent contaminants within the combustion chamber from entering the chamber face of the volume of powder.

It may be noted that the manufacturing process of this invention is quite different than conventionally used in making dielectric powder filled conduit. In the manufacture of conduit there is a step to soften the powder in the conduit so that it will flow with respect to the inner and outer conductors when the conduit is bent, and a step to anneal the outer conductor. In contradistinction, the igniter of this invention must be rigid and permit no relative movement of its internal elements. The pressure pulses apply extremely high pressure on the surface and interior interfaces of the volume of powder. No give or movement of the outer tube or internal elements is permitted. In the conventional conduit there is no pressure on the surface or interior interfaces of the powder in the tube.

It should be noted that the invention herein is not limited to a single inner conductor, a plurality of mutually spaced apart conductors may be supported by the particles of dielectric material and held by the outer tube.

What is claimed is:

1. A gun comprising:

a gun barrel having a projectile receiving cavity, and an igniter including

an outer tubular element having a conductive inner surface;

an inner element substantially coextensive longitudinally with said outer element and having a conductive outer surface;

a volume, free of internal voids, of closely packed particles of dielectric material, disposed between and interlocked with said inner and outer elements, the peripheral particles of said volume being partially imbedded into said conductive surfaces of said inner and outer elements;

said volume extending less than the full length of said inner element to provide a void at a first end of said igniter, said void being defined by an exposed portion of said conductive surface of said inner element mutually confronting an exposed portion of said conductive surface of said outer element, and the end face of said volume;

sealing means including a solid annulus of dielectric material disposed within said void, in abutment with said end face of said volume and said conductive surfaces of said inner and outer elements, said annulus, said exposed portion of said conductive surface of said inner element and said exposed portion of said conductive surface of said outer element defining a spark chamber which is in fluid flow communication with said projectile receiving cavity.

2. A gun according to claim **1** further including:

a volume of liquid propellant disposed in said projectile receiving cavity and extending into said spark chamber.

3. A gun according to claim **1** further including:

a gun bolt having a bolt face and a bore extending longitudinally therefrom;

said igniter fixed in said bore of said gun bolt and radially supported thereby, with said spark chamber opening onto said bolt face;

means for inserting said gun bolt into said projectile receiving cavity.

4. A gun according to claim **3** wherein:

said igniter has a first longitudinal portion including said first end of a first diameter, a second longitudinal portion spaced from said first end of a second diameter, said second diameter being smaller than said first diameter, and a transition between said portions;

said bore of said gun bolt has a first longitudinal portion adjacent said bolt face of said first diameter and a second longitudinal portion spaced from said bolt face of said second diameter, and a transition between said portions;

said bolt transition abutting said igniter transition to provide longitudinal support thereto.

5. A gun according to claim **1** wherein:

said igniter is made by the process of

providing an assembly of an outer tube of conductive metal, an inner rod of a conductive metal, and an intermediate volume of particles of dielectric material concentrically spacing said rod within said tube;

compressing the outer tube radially about said intermediate volume and the rod to remove all voids in said intermediate volume and to imbed the peripheral particals of said volume into the adjacent surfaces of said tube and rod.

6. A gun according to claim **5** further including:

removing a portion of said volume after said compressing step to provide said void at said first end of said volume.

7. A gun according to claim **6** further including:

fixing said igniter into said bore of said bolt.

8. An igniter comprising:

an outer tubular element having a conductive inner surface;

an inner element substantially coextensive longitudinally with said outer element and having a conductive outer surface;

a volume, free of internal voids, of closely packed particles of dielectric material, disposed between and interlocked with said inner and outer elements.

the peripheral particles of said volume being partially imbedded into said conductive surfaces of said inner and outer elements;

said volume extending less than the full length of said inner element to provide a void at a first end of said igniter, said void being defined by an exposed portion of said conductive surface of said inner element mutually confronting an exposed portion of said conductive surface of said outer element, and the end face of said volume;

sealing means including a solid annulus of dielectric material disposed within said void, in abutment with said end face of said volume and said conductive surfaces of said inner and outer elements, said annulus, said exposed portion of said conductive surface of said inner element and said exposed portion of said conductive surface of said outer element defining a spark chamber;

said igniter being made by the process of

providing an assembly of an outer tube of conductive metal, an inner rod of a conductive metal, and an intermediate volume of particles of dielectric material concentrically spacing said rod within said tube;

compressing the outer tube radially about said intermediate volume and the rod to remove all voids in said intermediate volume and to imbed the peripheral particles of said volume into the adjacent surfaces of said tube and rod.

9. An igniter according to claim 8 further including: removing a portion of said volume after said compressing step to provide said void at said first end of said volume.

10. An igniter according to claim 9 further including: fixing said igniter into an additional tube to provide additional radial support to said outer tube.

* * * * *

United States Patent [19]

Ashley

[11] **4,102,269**

[45] **Jul. 25, 1978**

[54] **LIQUID PROPELLANT WEAPON SYSTEM**

[75] Inventor: **Eugene Ashley,** Burlington, Vt.

[73] Assignee: **General Electric Company,** Burlington, Vt.

[21] Appl. No.: **778,770**

[22] Filed: **Mar. 17, 1977**

[51] **Int. Cl.**[2] **F42B 5/16;** F42B 9/14

[52] **U.S. Cl.** .... **102/38 LP;** 89/7

[58] **Field of Search** .... 102/38 R, 40, 43 R, 102/24 R, 38 LP, 38 CC; 89/7

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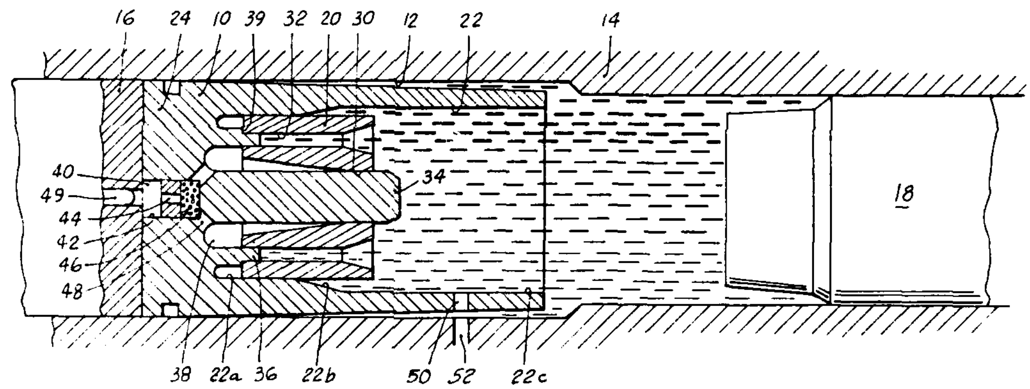
Primary Examiner—David H. Brown

Attorney, Agent, or Firm—Bailin L. Kuch

[57] **ABSTRACT**

This invention provides a gun and ammunition system utilizing a liquid propellant traveling charge provided by a cavity generator which programs the dynamics of ignition and combustion.

11 Claims, 2 Drawing Figures



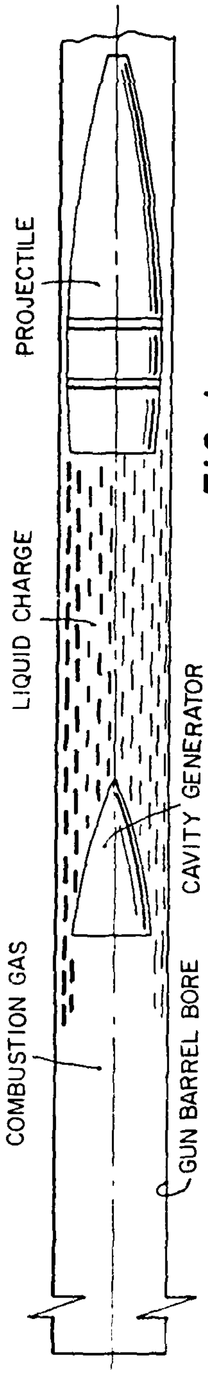


FIG. 1
(PRIOR ART)

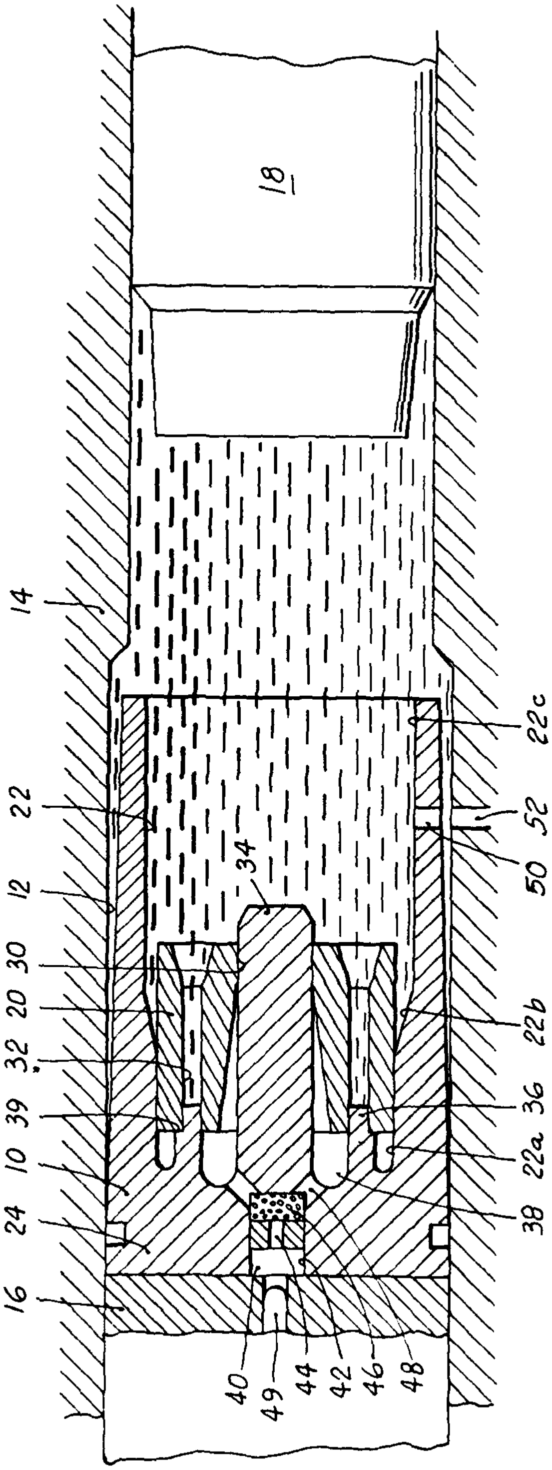


FIG. 2

LIQUID PROPELLANT WEAPON SYSTEM

The U.S. Government has rights in this invention pursuant to Contract No. N00123-76-C-0164 awarded by the Department of Defense.

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates to weapon systems employing bulk loaded liquid propellant.

2. Prior Art

The interior ballistics of bulk loaded liquid propellant guns has been the subject of study for a number of years. In my earlier U.S. patent application, Ser. No. 575,283, filed May 7, 1975, now U.S. Pat. No. 4,011,817, I disclosed a mechanical adaptation of the Taylor theory of cavity formation as a means for both controlling the propellant burning rate and achieving a down-bore traveling charge effect. The traveling charge effect is to be achieved through a subcaliber body of revolution placed at the rear of the liquid charge. Termed the "cavity generator", the body of revolution is designed to penetrate the liquid charge during the combustion process and to control the rate at which propellant is supplied to the combustion zone. FIG. **1** illustrates the basic system. A projectile, a propellant charge and a cavity generator are shown at a down-bore position part way through the firing process. Acceleration is to the right. The cavity generator separates the bulk of the liquid charge in front of it from the combustion zone behind it. The cavity generator is less dense than the liquid it displaces. The density difference gives rise to a force which causes the cavity generator to move forward into the liquid. As the cavity generator penetrates the charge, propellant flows rearward in a relative sense into the combustion zone. This action continues until the penetration is complete and all of the propellant has been burned.

SUMMARY OF THE INVENTION

An object of this invention is to provide a gun and ammunition system utilizing a liquid propellant traveling charge provided by a cavity generator which programs the dynamics of ignition and combustion.

A feature of this invention is the provision of a cavity generator having a plurality of longitudinal bores respectively receiving a plurality of rods fixed to the aft end of the combustion chamber. The interengagement of the bores and rods secures the generator, and provides an initiating chamber behind the cavity generator. An ignition system generates hot gas within the initiating chamber to initiate the firing of the round.

BRIEF DESCRIPTION OF THE DRAWING

These and other objects, features and advantages of this invention will be apparent from the following specification thereof taken in conjunction with the accompanying drawing in which:

FIG. **1** is a schematic view of a gun and ammunition system as disclosed in Ser. No. 575,283; and

FIG. **2** is a longitudinal cross-section of a gun and ammunition system embodying this invention.

DESCRIPTION OF THE INVENTION

FIG. **2** shows a stub-case, dry loaded, in-the-gun-filled round of ammunition. A stub case **10** is locked into a chamber **12** of a gun barrel **14** by a gun bolt **16**. A projectile **18** initially closes the open end of the stub case before propellant is introduced. A cavity generator **20** is disposed within the bore **22** of the case adjacent to but spaced from the base **24** of the case. The bore **22** has a portion of smallest diameter **22*a*** adjacent the base **24**, a portion of enlarging diameter **22*b***, and a portion of largest diameter **22*c*** adjacent the mouth of the case.

The generator **20** is of generally cylindrical shape and as shown has a central, longitudinally extending, tapered, large diameter bore **30**, and plurality of longitudinally extending, smaller diameter bores **32** disposed in an annular row concentric with the bore **30**. Additional bores and rows may be provided. A central, large diameter rod **34** extends longitudinally from the base **24**, into and through the bore **30**, and a like plurality of shorter rods **36**, disposed in an annular row, extend longitudinally from the base respectively into the bores **32**. The aft face of the generator and the forward face of the base, together with the case side wall and the rods, define an initiating volume or chamber **38**. Shoulders **39** may be provided to limit aftward movement of the generator within the case.

A primer **40** is fixed in a cup **42** in the aft face of the base and communicates through a flash bore **44** with a booster charge **46** in the cup, which cup communicates through a plurality of flash bores **48** with the initating volume **38**. The primer may be initiated by a firing pin **49** in the bolt **16**, and with the booster, serves as an ignition system which provides hot gas to the initiating volume to initiate the firing process.

Liquid propellant is charged into the bore **22** of the case through a port **50** through the side wall of the case from a valving system **52** in the gun. The charge of liquid propellant displaces the projectile forwardly into the bore **54** of the gun barrel **14**. Propellant is thus disposed aft of the projectile **18** and forward of the cavity generator **20** and inside any open portion of the bores **32** in the generator forward of the rods **36**. The number, pattern and shape of the bores and rods may be varied to control the degree to which the bores remain filled with gas, as will be explained later. By means of their interfitting with the bores in the generator, the rods support the generator at the rear of the case before firing and also serve to separate the liquid propellant from the initiating volume.

The firing sequence is as follows:

1. The primer **40** is fired, igniting the booster charge **46**, to fill the initiating volume **38** with hot gas.
2. At first the cavity generator **20** acts like a simple piston. It begins to move forwardly, compressing the propellant, pushing the projectile forward so that the forcing cone and rifling engrave the rotating band of the projectile to begin the accelerating process. The length of the rods prevent the exposure of liquid propellant to the hot gas.
3. Subsequently, the cavity generator moves off the shortest rods **(36)** to expose propellant to the hot gas. Combustion of the adjacent propellant commences. This propellant will generate combustion gasses behind the cavity generator to further the piston action of the cavity generator in the accelerating process.
4. Finally, the large diameter center hole, which is intentionally filled with gas by making it tapered, begins to progress off the center rod. The hot gas will go out forwardly because the column of liquid ahead of it is short. The main combustion bubble from the central bore, and possibly additional bub-

bles from the smaller bores, if the smaller bores are also tapered, advance forwardly into the main charge of liquid propellant, leaving the cavity generator behind in the stub case. The generator is ultimately extracted with the case.

In this manner the size, number and sequence in time of the combustion bubbles or cavities entering the main charge of liquid propellant can be controlled.

What is claimed is:

1. A round of ammunition comprising:

a projectile having a first average density;

a cavity generator having a second average density;

a charge of liquid propellant having a third average density which is greater than said second average density; and

a cartridge case;

said cavity generator having a forward face, an aft face, and a passageway extending longitudinally therebetween; and

said cartridge case having means for obturating said passageway.

2. A round of ammunition according to claim 1 wherein:

said cartridge case has a base with an interior forward face;

said cavity generator is disposed with its aft face forward of and spaced from said case base face, and therebetween defining an initiating volume.

3. A round of ammunition according to claim 2 wherein:

said cavity generator includes an additional passageway extending longitudinally between said forward and aft faces of said cavity generator; and

said cartridge case includes an additional means for obturating said additional passageway; and

further including

means for supplying hot gas into said initiating volume, for advancing said cavity generator from a first station whereat said first mentioned passageway is closed by said first mentioned obturating means and said additional passageway is closed by said additional obturating means, to a second station whereat said additional passageway is opened by said additional obturating means and liquid propellant passes through said additional passageway into said initiating volume and is ignited by said hot gas, and thereafter, to a third station whereat said first mentioned passageway is opened by said first mentioned obturating means and hot gas passes through said first mentioned passageway from said initiating volume into said liquid propellant charge.

4. A round of ammunition according to claim 3 wherein:

said first mentioned passageway has a decreasing cross-sectional area from said aft face to said forward face of said cavity generator; and

said first mentioned obturating means is a longitudinally extending rod having a substantially uniform cross-sectional area along its length.

5. A round of ammunition according to claim 3 wherein:

said first mentioned passageway comprises a substantially conical bore of decreasing cross-sectional area from said aft face to said forward face of said cavity generator; and

said first mentioned obturating means is a longitudinally extending cylindrical rod of substantially uniform cross-sectional area along its length.

6. A round of ammunition according to claim 2 further including:

means for supplying hot gas into said initiating volume, for advancing said cavity generator forwardly from a first station whereat said passageway is closed by said case obturating means to a second station whereat said passageway is opened by said case obturating means and liquid propellant passes through said passageway into said initiating volume and is ignited by said hot gas.

7. A round of ammunition according to claim 2 further including:

means for supplying hot gas into said initiating volume, for advancing said cavity generator forwardly from a first station whereat said passageway is closed by said case obturating means to a second station whereat said passageway is opened by said case obturating means and hot gas passes therethrough from said initiating volume into said liquid propellant charge.

8. A round of ammunition according to claim 7 wherein:

said first and second stations of said cavity generator are longitudinally spaced apart within said cartridge case.

9. A round of ammunition according to claim 8 wherein:

said passageway in said cavity generator tapers from a relatively larger diameter at said aft face to a relatively smaller diameter at said forward face.

10. A round of ammunition according to claim 5 wherein:

said cavity generator includes a first plurality of additional passageways extending longitudinally between said forward and aft faces of said cavity generator; and

said cartridge case includes a second plurality, equal to said first plurality, of additional means for respectively obturating each of said additional passageways.

11. A round of ammunition according to claim 10 wherein:

said first station of said cavity generator is identical for said first mentioned passageway and said first plurality of additional passageways; and

said first plurality of additional passageways is opened by said second plurality of additional case obturating means at an intermediate station disposed longitudinally between said first station and said second station.

* * * * *

United States Patent [19]

Ashley

[11] **4,126,078**

[45] **Nov. 21, 1978**

[54] **LIQUID PROPELLANT WEAPON SYSTEM**

[75] Inventor: **Eugene Ashley**, Burlington, Vt.

[73] Assignee: **General Electric Company**, Burlington, Vt.

[21] Appl. No.: **839,476**

[22] Filed: **Oct. 4, 1977**

Related U.S. Application Data

[62] Division of Ser. No. 707,143, Jul. 20, 1976, Pat. No. 4,069,739.

[51] **Int. Cl.**[2] **F41F 1/04**; F42B 9/12

[52] **U.S. Cl.** .... **89/7**; 89/1.701; 102/38 LP

[58] **Field of Search** .... 102/38 R, 38 CC, 38 LP; 89/7, 8, 1.701, 1.7 R, 1.703, 1.704, 1.706

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Primary Examiner—David H. Brown
Attorney, Agent, or Firm—Bailin L. Kuch

[57] **ABSTRACT**

A gun and ammunition system utilizing a round of ammunition which contains a supply of liquid propellant and after ignition pumps this propellant into the combustion chamber of the gun.

2 Claims, 21 Drawing Figures

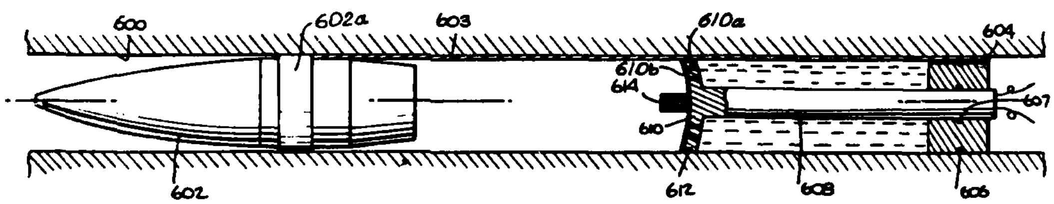


Fig. 1.

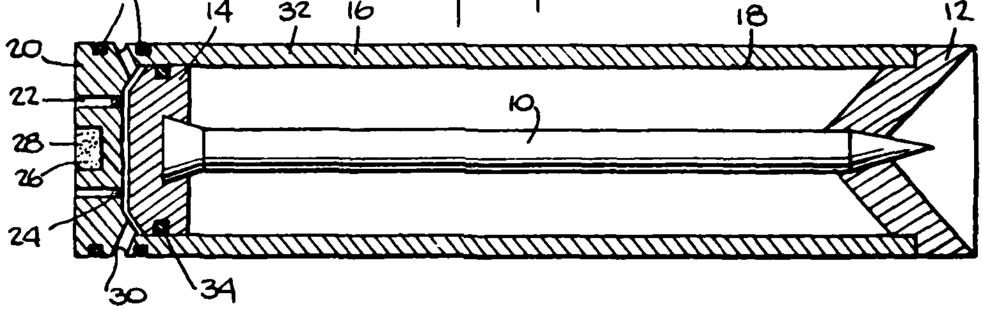


Fig. 3.

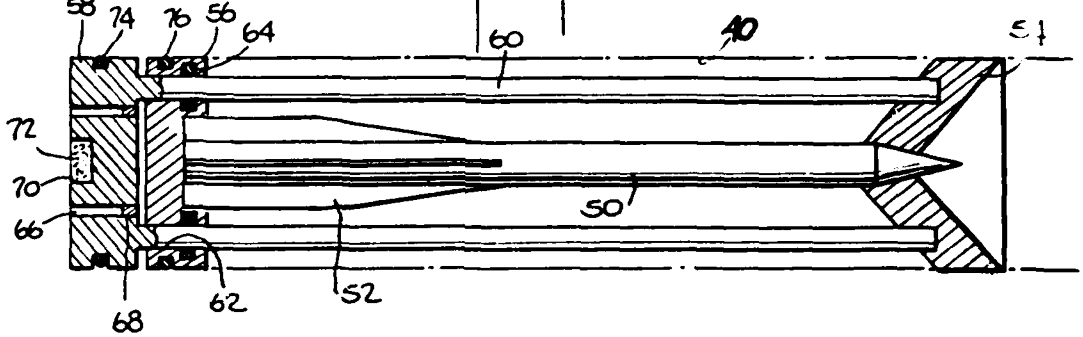
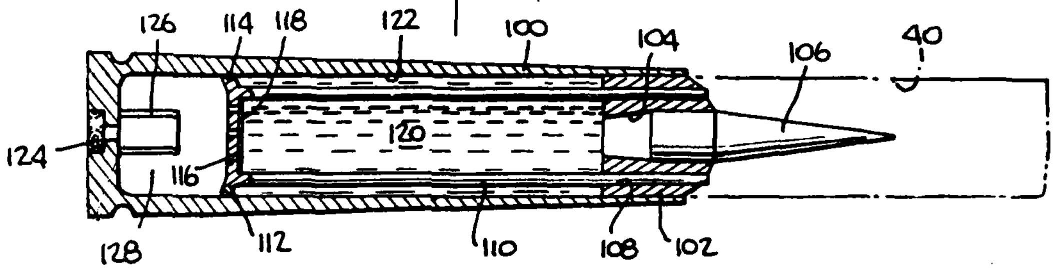


Fig. 4.



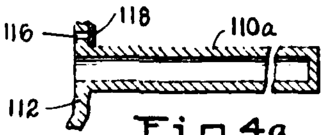


Fig. 4a

Fig. 5.

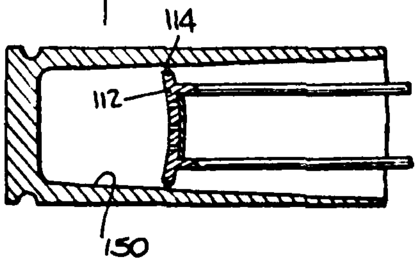
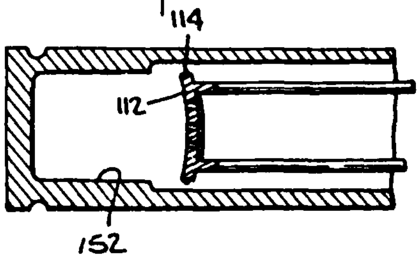


Fig. 6.



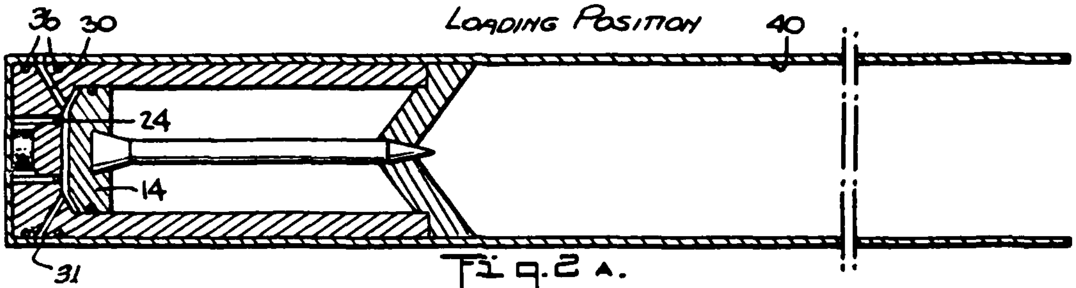


Fig. 2A.

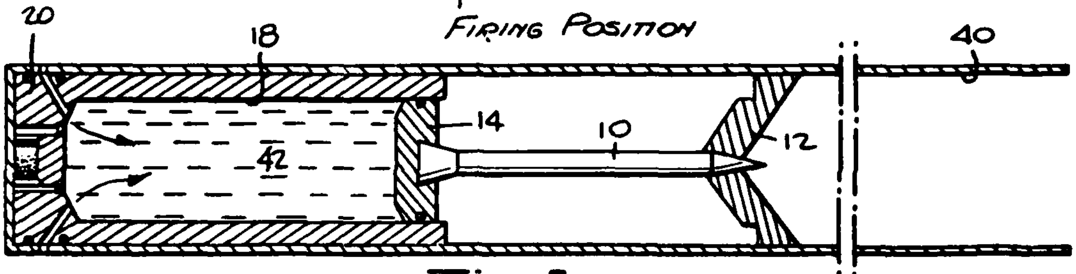


Fig. 2B.

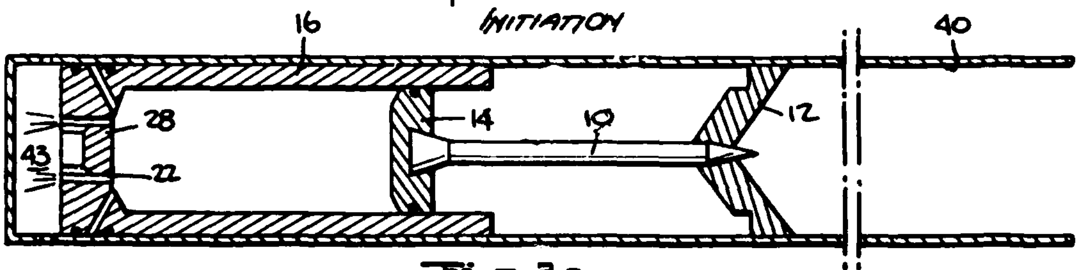


Fig. 2C.

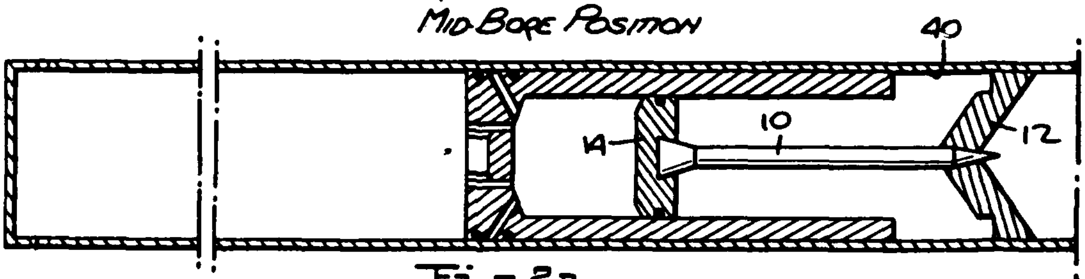


Fig. 2D.

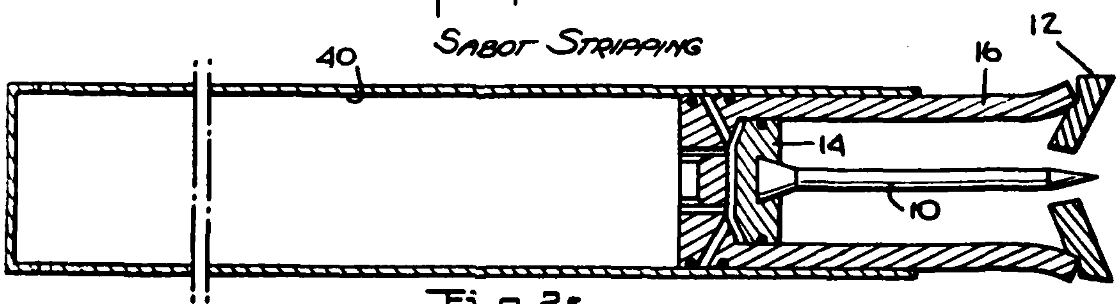


Fig. 2E.

Fig. 8.

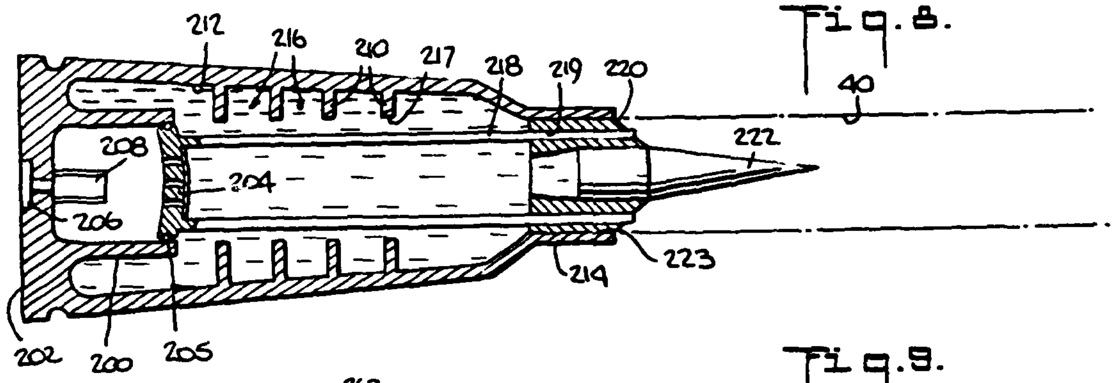


Fig. 9.

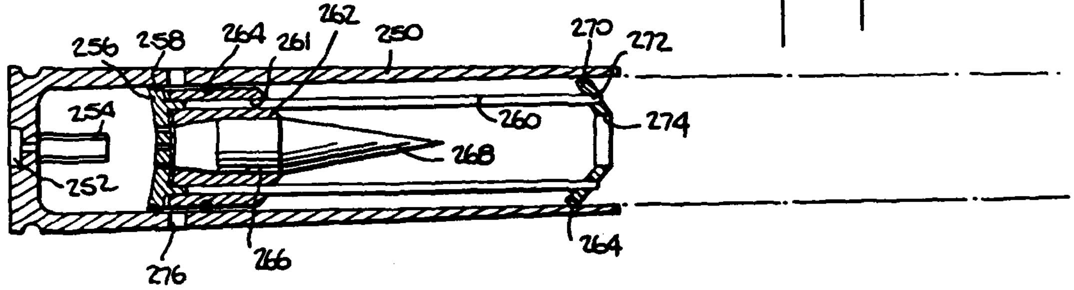


Fig. 10.

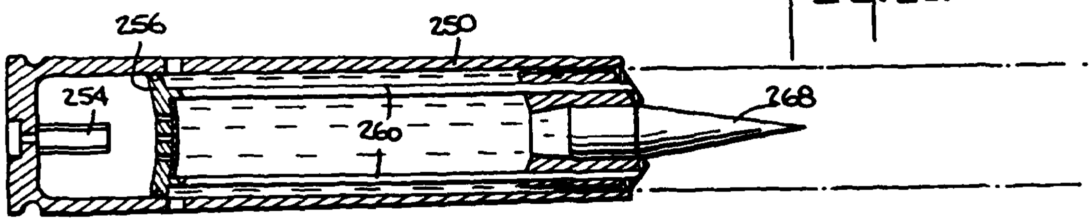
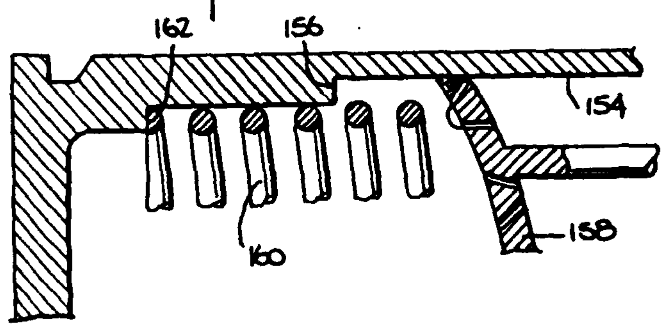


Fig. 7.



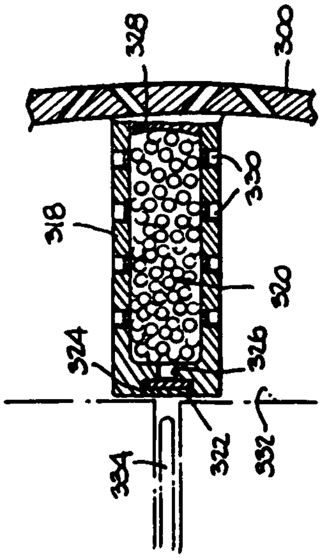


Fig.13.

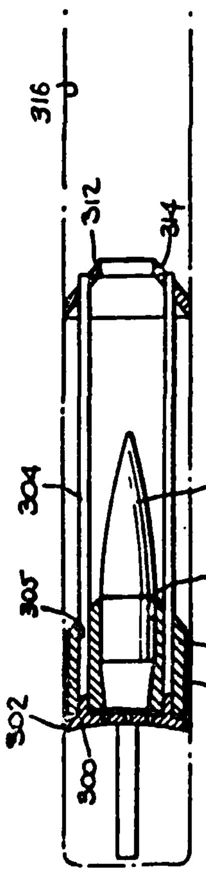


Fig.11.

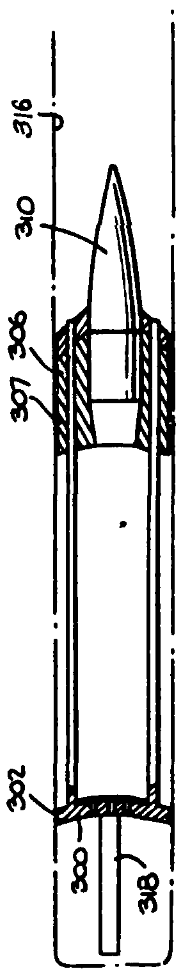


Fig.12.

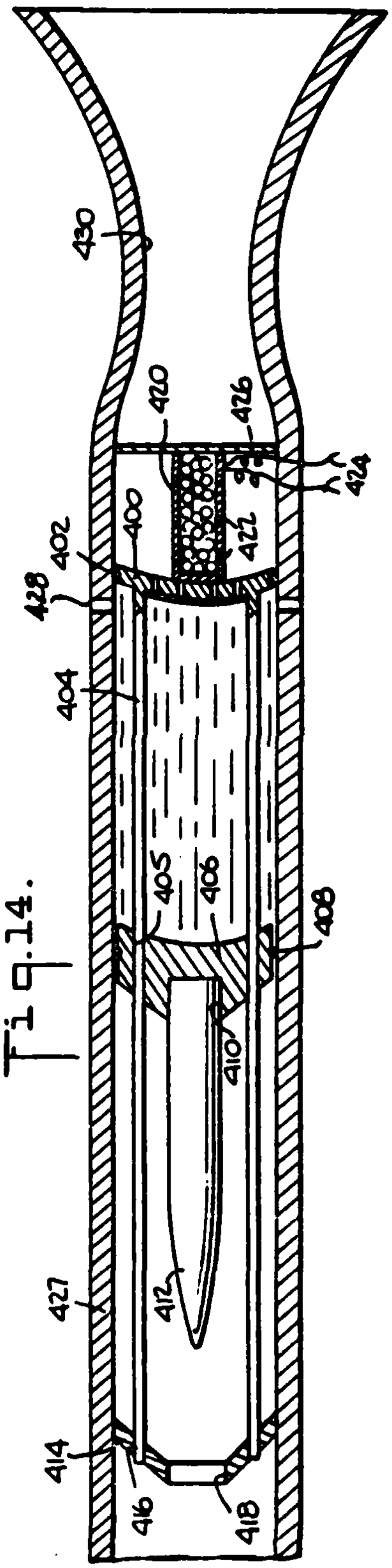


Fig.14.

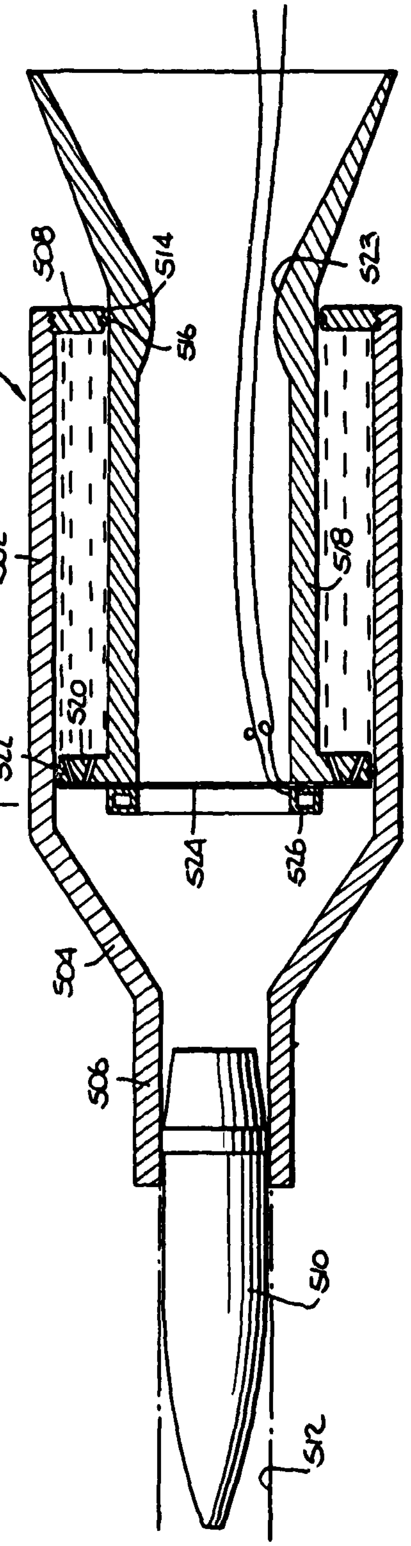

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Fig. 15.

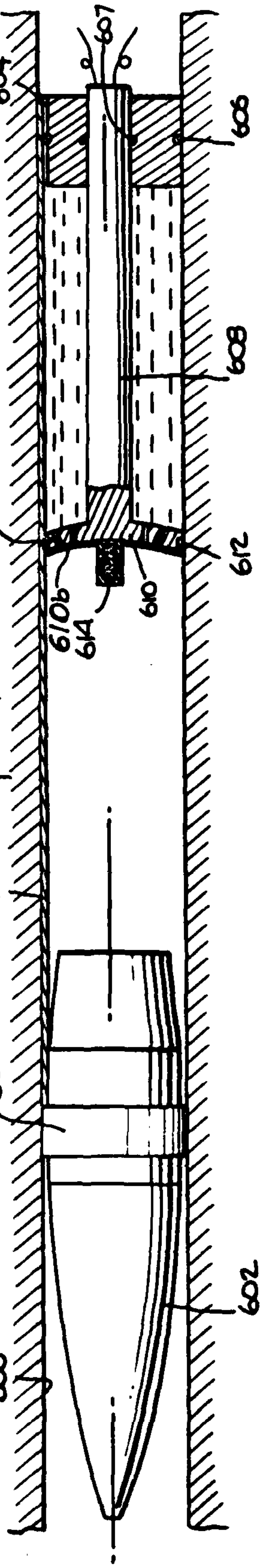
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Fig. 16.

LIQUID PROPELLANT WEAPON SYSTEM

This application is a division of Ser. No. 707,143, filed July 20, 1976, now U.S. Pat. No. 4,069,739.

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates to weapon systems employing a liquid propellant, and particularly to such systems wherein the propellant is continuously pumped into the combustion chamber as the projectile advances along the firing bore.

2. Prior Art

Weapons systems providing traveling charge effects on projectiles, or rockets, or other related systems, are shown, for example, in U.S. Pat. Nos. 3,431,816; 3,411,403; 3,459,101; 3,496,827; 3,601,056; 3,613,499; 3,628,457; 3,648,616; 3,665,803; 3,696,749; 3,698,321; 3,712,171; and 3,728,937. In a final report for the Bureau of Ordnance, Department of the Navy, under Contract NOrd 16217 Task 1, dated Sept. 1, 1957, work was described on a propellant carrying projectile. "This projectile contained approximately 100 grams of a hydrazine, hydrazine nitrate, water monopropellant (63, 32, and 5% by weight respectively). Upon ignition of the primary bipropellant charge in the breech, regenerative injection of the bipropellants progresses in the usual manner, and the projectile is accelerated. The accelerating forces upon the projectile components are so adjusted as to produce relative motion between the projectile body and the center plunger. This motion expels the extrapped monopropellant rearward past the fragile seal disk into the hot combustion chamber gases, where it burns while the projectile is accelerated." The projectile apparently comprised a forward solid cylindrical projectile whose outer wall engaged the inner wall of the firing bore, an intermediate, longitudinally central rod journaled through a bore in the projectile, and an aft sealing disk fixed to the rod and whose periphery engaged the inner wall of the firing bore. The monopropellant was trapped between the forward cylindrical projectile and the aft disk within the firing bore. Solid primary charges were also used in lieu of liquid primary charges. A separate static sealing disk was also used in lieu of the peripheral seal on the aft sealing disk.

SUMMARY OF THE INVENTION

It is an object of this invention to provide a gun and ammunition system for launching rod-shaped projectiles at high velocity.

It is an additional object to provide such a system utilizing liquid propellants.

A feature of this invention is the provision of a gun and ammunition system utilizing a round of ammunition which contains a supply of liquid propellant and after ignition pumps this propellant into the combustion chamber of the gun.

An additional feature of this invention is the provision of a gun and ammunition system utilizing a round of ammunition carrying a relatively narrow diameter and relatively high mass projectile in a relatively wide and relatively low mass sabot, which is initially accelerated by a primary propellant charge in the combustion chamber aft of the projectile and which is subsequently accelerated by a secondary propellant charge in the round which is passed during a relatively extended period of time to the combustion chamber.

BRIEF DESCRIPTION OF THE DRAWING

These and other objects, features and advantages of this invention will be apparent from the following specification thereof taken in conjunction with the accompanying drawing in which:

FIG. 1 is a view in longitudinal cross-section of an idealized round of ammunition having a sabot and a system to regeneratively pump liquid propellant, the round is here shown in its telescoped, minimum length configuration, without liquid propellant;

FIG. 2A through E respectively illustrate, within the gun bore, the

(A) before charging with liquid propellant configuration,

(B) after charging with liquid propellant and ready for initiation of the primer configuration,

(C) shortly after initiation and commencement of injection of liquid propellant into the combustion chamber configuration,

(D) midbore configuration, and

(E) bore exiting and sabot stripping configuration,

in the sequence of operations of the round of FIG. 1;

FIG. 3 is a view in longitudinal cross-section of a second embodiment of this invention;

FIG. 4 is a view in longitudinal cross-section of a third embodiment of this invention;

FIG. 4*a* is a detail of a variant of the embodiment shown in FIG. 4;

FIGS. 5 and 6 are views in longitudinal cross-section of a fourth embodiment of this invention;

FIG. 7 is a view in longitudinal cross-section of a fifth embodiment of this invention;

FIG. 8 is a view in longitudinal cross-section of a sixth embodiment of this invention;

FIGS. 9 and 10 are views in longitudinal cross-section of a seventh embodiment of this invention;

FIGS. 11, 12 and 13 are views in longitudinal cross-section of an eighth embodiment of this invention;

FIG. 14 is a view in longitudinal cross-section of a ninth embodiment of this invention;

FIG. 15 is a view in longitudinal cross-section of a tenth embodiment of this invention; and

FIG. 16 is a view in longitudinal cross-section of an eleventh embodiment of this invention.

DESCRIPTION OF THE EMBODIMENTS

Rod shaped penetrators launched at high velocities from medium caliber guns are effective against some types of armor. Since rod penetrators are characteristically long and thin, sabot launching techniques are conventionally employed. The sabot in this case is essentially a light weight piston of diameter larger than the penetrator, and which supports the heavier penetrator. In the launching or firing process, the combustion gas acts against the area of the full diameter of the sabot, rather than against the rod alone, in accelerating the two in combination.

Liquid propellants have several desirable characteristics, such as relatively low flame temperature and ease of storage and handling. A major problem in the use of liquid propellants lies in the control of the ballistic process in the combustion chamber. Propellants can be either placed in the chamber before firing and then be ignited; or it can be metered into the chamber during the combustion process. The last mentioned, sometimes

called preloading, is easier to do mechanically, but permits little control over burning after ignition. U.S. Pat. No. 3,763,739 issued to D. P. Tassie on Oct. 9, 1973, discloses a gun system of this type. The second mentioned, sometimes called forced injection, permits control over the rate of burning through control over the rate of introduction of the propellant, but involves extremely high pumping pressures. Such high pressures pose stringent requirements on seals, fittings and structural components. If the energy for forced injection is to be supplied from an external source, the power requirements are very high. For example, the power required to pump three cubic inches of propellant across a pressure drop of 10,000 psi in 20 milliseconds is 227 hp. This can be averaged over a larger period in an actual gun to lower the peak value, but the power requirement is still unreasonable.

An effective solution to the power requirement for pumped injection is to utilize the combustion chamber pressure itself as the source of energy for pumping. Called regenerative injection, this scheme uses a differential area piston for each propellant. The larger end of the piston is acted on by the chamber pressure, and the smaller end pressurizes the propellant to be injected. The difference in areas generates a propellant pressure sufficiently high than the chamber pressure to achieve the desired rate of injection.

FIRST EMBODIMENT

Turning now to FIG. 1, a first embodiment of the invention is shown as an idealized round of ammunition having a sabot and regenerative, liquid propellant pumping system, for use in a gun which will fill the round with propellant before firing. The penetrator 10 is here shown as a rod which upon launching will be drag stabilized. The sabot is a three piece assembly, comprising an annular nose stabilizer 12 fixed to the forward end of the penetrator, a circular pusher-plate 14 fixed to the aft end of the penetrator, and a cylindrical body 16. The body 16 has an internal bore 18 closed at its aft end 20, which bore receives the plate 14. The aft end 20 serves as an injector plate and has a pluralitv of longitudinal bores 22 therethrough serving as injection passageways. Each bore is obturated by a respective plug 24. An aft recess 26 receives a primary propellant charge, here shown as a solid primer 28. One or more substantially radially oriented bores 30 pass through the side wall 32 of the body into the interface between the plate 20 and the plate 14, to serve as propellant fill passageways. An annular seal 34 is provided on the periphery of the plate 14, and a pair of annular seals 36 are provided on the periphery of the body 16 straddling the fill passageways.

The plugs 24 may be embodied as relief valves, individual plugs, a burst diaphragm fixed to the forward face of the injector plate, or simply portions of the bore material not fully drilled through, all of which will shear or open at the desired pressure level.

The penetrator and sabot assembly may be preloaded with liquid propellant through the fill passageways, which are then plugged, before being placed in the gun. Alternatively, the assembly may be placed in the firing bore 40 of the gun and then loaded with propellant. The actual firing process is the same for each scheme, and loading within the gun will be discussed with respect to FIGS. 2A through 2C.

As shown in FIG. 2A, the penetrator and sabot assembly, still without its propellant charge, has been placed into the breech of a gun barrel and the breech has been closed. The fill passageways 30 are aligned with suitable fil; ports 31 in the breech wall of the gun, such as are shown in U.S. Pat. No. 3,763,739, supra, which must incorporate high pressure fill valves or check valves which can withstand firing pressure. These passageways serve as means for providing liquid propellant to the round of ammunition in the firing bore.

As shown in FIG. 2B, propellant is pumped into the interface between the injector plate 20 and the pusher plate 14, progressively pushing the pusher plate forward within the bore 18 to create an injection volume 42 which receives a complete charge. Stops can be provided to halt the forward advance of the nose stabilizer, or preferably, the charge can be metered. The round is shown fully charged and ready for firing.

As shown in FIG. 2C, firing is initiated by setting off the primer, which rapidly generates a small volume of high pressure, hot gas in the space 43 aft of the injector plate which serves as the combustion chamber. This high pressure aft of the loaded round produces an immediate acceleration of the complete round. The overall force producing the acceleration, which force is equal to the chamber pressure times the chamber cross-sectional area, is exerted against the aft face of the injector plate. The penetrator and sabot assembly has a relatively high weight relative to the weight of the body 16 with a correspondingly relatively high inertia. A portion of the accelerating force is absorbed in accelerating the body 16 per se, but the remainder of the accelerating force is transmitted by the forward surface of the injector plate against the charge of liquid propellant. The resultant pressure developed in the liquid is the transmitted force divided by the liquid or injection volume cross-sectional area. When the ratio of the areas of the aft face of injector plate and the injection volume, and the body weight and the total round weights are properly predetermined, a liquid pressure will be generated which is higher than the chamber pressure as follows:

$$\frac{P_L}{P_C} = \frac{A_C}{A_L}\left(1 - \frac{W_B}{W_{TOT}}\right)$$

where

P_L is liquid pressure,
P_C is chamber pressure,
A_C is chamber area,
A_L is liquid area,
W_B is body weight, and
W_{TOT} is the sum of the body, the liquid and the penetrator and sabot assembly weights.

The difference between the two pressures P_L and P_C is the driving force which can be utilized for regenerative injection.

The plugs 24 are designed to open at a predetermined difference in pressure between the interior volume and the combustion chamber. These plugs serve as a pressure sensitive obturating means. As shown in FIG. 2C, when this difference is reached, the plugs will open and propellant will flow into the chamber. The injection passageways 22 serve to atomize or break up the propellant streams through techniques similar to those used in rocket injector design. As the propellant streams initially encounter the hot primer gases they ignite, generating more hot gas. Incoming propellant continues to ignite and the process becomes self-sustaining, and gen-

erates increasing chamber pressure, which accelerates the process. The process continues until the propellant is expended. Meanwhile, the whole round is being accelerated along the bore by what is in effect, a traveling charge. FIG. 2D shows the round at mid-bore length with the propellant partially expended.

As the round leaves the muzzle, the sabot fore and aft supports are stripped from the penetrator which continues on its course. FIG. 2E shows the nose stabilizer 12 acting under wind forces to open the body 16 and free the penetrator.

The entire body 16 is here shown as engaging the rifling of the bore 40 to provide spin to the entire round if a spin stabilized projectile is used. Alternatively a lesser annular portion of the body may engage the rifling.

SECOND EMBODIMENT

Frictional forces are developed between the body 16 and the interior wall of the bore 40 as the round is launched, which are a function of the materials of the body 16 and the bore 40 of the gun barrel. An alternative embodiment which minimizes such frictional forces is shown in FIG. 3.

The penetrator 50 is here shown as a rod which is stabilized by a plurality of fins 52. The sabot is a three piece assembly comprising an annular nose stabilizer 54 fixed to the forward end of the penetrator, a circular pusher-plate 56 fixed to the aft end and an injection plate 58 having a plurality of forwardly, longitudinally extending, integral rods 60. The pusher plate 56 has a like plurality of longitudinal bores 62 with respective annular seals 64 each passing a respective one of the rods 60. The injector plate 58 also has a plurality of longitudinal bores 66 therethrough each obstructed by a respective plug 68, and an aft recess 70 receiving a primary propellant charge 72, all similar to the embodiment of FIG. 1. These plugs serve as a pressure sensitive obturating means. An annular seal 74 is provided in the periphery of the injector plate, and an annular seal 76 is provided in the periphery of the pusher plate. This penetrator and sabot assembly is disposed in the gun for filling with propellant with the fill ports in the breech wall of the gun aligned with the interface between the injection plate and the pusher plate.

The use of the rods 60 upon which the pusher plate can slide permits the omission of the body structure, so that only the peripheries of the pusher plate, the injector plate and the stabilizer need contact the wall of the barrel bore 40. The liquid propellant is contained between the pusher plate, the injector plate and the wall of the barrel bore. The necessary differential in areas is provided by the total cross-sectional areas of the rods 60. The rods provide an added advantage in the sabot stripping phase of the launching cycle as they are relatively weaker and therefore easier to deflect radially outwardly than the equivalent cylindrical body 16.

Both of the embodiments described above provide the following advantages:

1. Controlled injection is achieved through regenerative pumping action;

2. The inertia of the projectile itself is the source of the pumping force;

3. The injection mechanism is incorporated into the penetrator and sabot assembly, with very little effect on the gun design;

4. A traveling charge effect is achieved;

5. The injection system and high pressure seals are used only once for each shot and are then discarded.

6. The sabot and projectile assemblies may be stored and transported as essentially inert, considering the primer to be relatively insignificant. The assemblies do not become active until the introduction of the propellant. This can be delayed until after chambering and locking in the gun.

The specification so far has dealt with idealized projectile and sabot assemblies and their launching techniques. Cartridges embodying such assemblies may be provided in at least several different configurations.

THIRD EMBODIMENT

FIG. 4 shows the simplest pre-filled cartridge case embodiment. The projectile and sabot assembly are crimped into a cartridge case 100. The assembly comprises a forward annulus 102 which serves as a pusher plate and has a central bore 104 receiving a spin stabilized projectile 106 and a plurality of bores 108 disposed in an annular row, each receiving a respective one of a like plurality of rods 110 which are respectively fixed to an injector plate 112. The injector plate has an annular seal 114 fixed to its periphery and a plurality of longitudinal injection passageways 116 which are closed by a diaphragm 118 fixed to the forward face of the plate. The liquid propellant charge 120 is contained between the annulus 102, the plate 112 and the inner wall 122 of the case 100. The bore of the case includes an external primer 124 in communication with an internal booster tube 126 disposed in the combustion chamber 128 which is defined by the base of the case, the injector plate and the interior wall of the case. Upon ignition the injector plate and its rods move forwardly relative to the annulus, rupturing the diaphragm and injecting propellant into the combustion chamber. This diaphragm serves as a pressure sensitive obturating means. The inner wall 122 of the case is cylindrical and coplanar with the inner wall 40 of the bore of the gun barrel, so that the forward annulus and the injector plate smoothly leave the case and ride along the gun bore. The forward annulus may be made up of segments to provide ready rupture and release of the projectile when the assembly leaves the gun bore.

The injector plate 112 may be made of arched cross-section for a greater strength to weight ratio.

The rods 110 may be replaced with hollow tubes 110*a*, as shown in FIG. 4*a*, which are closed at their forward ends and open at their aft ends so that the interior volume of each tube communicates with and is at the same pressure as the combustion chamber 128. This permits the use of a thin wall tube whose wall thickness become progressively thinner from front to rear; since as the length of the tube exposed forwardly of the annulus 102 into the atmosphere increases, the combustion chamber pressure decreases.

FOURTH EMBODIMENT

In the embodiments discussed above, all of the injection of the propellant into the combustion chamber takes place through the passageways of the injector plate. An enlarged "Taylor cavity" will be formed by providing a tubular cylinder of propellant liquid in the combustion chamber as said chamber is being enlarged by the forward movement of the injector plate. The "Taylor cavity" provides a liquid-gas interface for combustion. This is accomplished by providing a variable internal diameter in the case which increases towards

the mouth of the case. As shown in FIG. 5, the bore 150 of the case may be tapered, or as shown in FIG. 6, the bore 152 of the case may be stepped to provide a variable, increasing, orifice for the liquid propellant around the periphery of the injector plate.

FIFTH EMBODIMENT

The injector plate should be prevented from moving aft under impulse loads exerted by the liquid propellant under conditions of vigorous handling or in the event a cartridge is dropped on its base. This can be accomplished by providing stops on the displacement rods aft of their engagement with the injector plate; a step can be provided in the interior wall of the case aft of the injector plate; or the injector plate may be fastened to the interior wall of the case by a weak joint which will rupture under the firing forces. To further minimize the effects of handling loads the stops may be made resilient. As shown in FIG. 7, the interior wall 154 may be provided with a step 156 to abut the outer margin of the injector plate 158. A helical spring 160 may be captured between an additional step 162 and the injector plate to resiliently fix the inputs plate and to permit it to move aft slightly before abutting the positive shoulder 156.

SIXTH EMBODIMENT

In the embodiment shown in FIG. 8, a prefilled case is provided which has an interior annular wall 200 extending from the base 202 which together with the injector plate 204 and its peripheral seal 205 defines an initial combustion chamber. An external primer 206 communicates with an internal booster 208 disposed in the initial combustion chamber. A plurality of rigid, spaced apart, partitions 210 extend inwardly from the interior wall 212 of case which is tapered progressively inwardly from the base to the neck 214 to provide a series of compartments 216 of decreasing volume, each opening into a central bore 217. As described with respect to FIG. 4, the injector plate is fixed to rods 218 which are journaled through respective bores 219 in an annulus 220 which retains the projectile 222. The bore 223 of the neck is coplanar with the gun bore 40. Liquid propellant is stored forward of the injection plate in the compartments 216 and in the central bore. The propellant in the central bore is injected into the combustion chamber by the injection plate as discussed with respect to FIG. 4. The propellant in each open compartment 216 tends to remain in place and to ignite as its compartment is exposed to the initial combustion chamber as the injection plate moves forward, also providing a "Taylor Cavity" effect.

SEVENTH EMBODIMENT

FIGS. 9 and 10 show a dry loaded cased cartridge embodiment, similar to the case of FIG. 4. The cartridge is provided with a case 250 having a primer 252 communicating with a booster charge 254, and a projectile and sabot assembly. The sabot includes an injector plate 256 having a peripheral seal 258 and a plurality of longitudinally extending rods 260 fixed thereto and respectively journaled through bores 261 in an annulus 262 which has a peripheral seal 264 and an axial bore 266 receiving a projectile 268. A stabilizing ring 270 is retained against non-firing loads aft of the mouth of the case as by cementing or crimping and has a like plurality of bores 272 journaling said rods 260 and an axial bore 274 adapted to pass the projectile. A plurality of radial bores 276 are disposed through the case in an annular row to serve as propellant filling passageways. In the stored configuration, as shown in FIG. 9, the annulus 262 is nested aft, close to the injector plate, without any liquid propellant, and the seals 258 and 264 straddling the row of bores 276. After the case has been loaded into the gun and the gun breech has been locked, the liquid propellant charge is pumped through aligned ports in wall of the breech of the gun as described with respect to FIG. 2B. The injector plate is prevented from aftward movement by suitable means, such as the stops described with respect to FIG. 7. As the liquid propellant charge is pumped into the interface between the injector plate and the annulus, it forces the annulus forward until it is stopped by the stabilizing ring, which provides an automatic metering device for the filling operation.

Both pre-loaded and dry-loaded cased cartridges share the following advantages:

1. Sealing of the breech is provided by the case.
2. The priming system is conveniently provided for each round.
3. A misfired round can be completely extracted by extracting the case.

The dry-loaded cartridge has the additional following advantages for shipping and handling:

1. The projectile is telescoped within the case for shipping and for loading into the gun. This minimizes the length of the parts to be handled.
2. The cartridge is relatively safe. In the absence of propellant, the primer and booster are the only combustible components present.
3. The propellant is loaded separately through control valves and piping. This can be controlled remotely if necessary.
4. The breech is closed before the propellant is charged into the cartridge, providing additional safety.

EIGHTH EMBODIMENT

FIGS. 11 and 12 show a dry-loaded uncased cartridge, which is loaded, locked, filled and fired in a manner similar to the cased cartridge of FIGS. 9 and 10. The sabot and projectile assembly comprises an injector plate 300 having a peripheral seal 302 and a plurality of longitudinally extending rods 304 fixed thereto and respectively journaled through bores 305 in an annulus 306 which has a peripheral seal 307 and an axial bore 308 receiving a projectile 310. A stabilizing ring 312 has a like plurality of bores 314 journaling said rods 304 and an axial bore 316 adapted to pass the projectile. As shown in FIG. 13, a primer and booster assembly comprises a sleeve 318 which cemented to the aft face of the injector plate 300. The sleeve is molded of solid propellant, of sufficient strength to provide a small combustion chamber 320 initially, but which will ultimately burn. A combustible primer 322 is fixed in a cup 324 in the exterior of the base of the sleeve and which communicates by a passageway 326 with the combustion chamber 320. The forward end of the sleeve is closed with a plug 328 which may be cemented. Radially extending flame passageways 330 are provided through the walls of the sleeve. These passageways are initially closed, as by plugs, being only partially formed through, or covered by a diaphragm. Loose powder is disposed in the combustion chamber.

The length of the primer and booster assembly is made equal to the length of the combustion chamber of the gun. When the cartridge is chambered and the breech is locked, the primer 322 is adjacent the face 332

of the breech block, and may be ignited by a conventional percussion firing pin **334**, or electrical firing means. The primer ignites the loose powder immediately, generating hot gases which rupture the flame passageway closures and pass into the combustion chamber. The molded combustible sleeve burns more slowly than the loose powder, but eventually all is consumed. The hot gas initiates the regenerative liquid propellant injection process as described previously.

The dry-loaded caseless cartridges have the following advantages:

1. The system is completely combustible. The gun chamber is completely empty after each shot.

2. The primary system is an integral part of the cartridge as supplied to the gun.

3. The primary system may be fabricated using conventional caseless ammunition technology.

NINTH EMBODIMENT

FIG. **14** shows a recoilless gun embodiment of a caseless cartridge similar to that shown at FIG. **12**. The sabot and projectile assembly comprises an injector plate **400** having a peripheral seal **402** and a plurality of longitudinally extending rods **404** fixed thereto and respectively journaled through bores **405** in an annulus **406** which has a peripheral seal **408** and an axial bore **410** receiving a projectile **412**. A stabilizing ring **414** has a like plurality of bores **416** journaling said rods **404** and an axial bore **418** adapted to pass the projectile. A priming system comprising a sleeve **420** which may be molded of solid propellant is cemented to the aft face of the injector plate **400**. The sleeve has radially extending flame passageways **422** which are initially closed and contains loose powder which may be ignited by an electrical firing system **424**. A frangible diaphragm **426** is cemented to the aft end of the sleeve. The initial combustion chamber is provided within the sleeve, and the subsequent combustion chamber is defined between the injection plate and the diaphragm. The diaphragm is adapted to burst at a pressure which is high enough to insure that initiating combustion has been achieved.

The gun **427** includes suitable ports **428** to pass liquid propellant to the interface between the injection plate **400** and the annulus **406**. The gun also includes a converging/diverging nozzle **430** in lieu of the conventional closed breech. This nozzle may be of the type shown, for example, in U.S. Pat. Nos. 2,444,949, 2,696,760, 2,790,353 and 3,610,093. The nozzle provides an expansion chamber and a venturi orifice therein to allow a sufficient amount of the combustion gases to expand and escape rearwardly, thereby stabilizing the gun against recoil. The nozzle may be made separable from the breech to permit loading of the cartridge. FIG. **14** shows the annulus **406** midway in its forward advance during the loading with liquid propellant.

TENTH EMBODIMENT

FIG. **15** shows a recoilless gun embodiment of a cased, preloaded cartridge. The cartridge includes a case **500** having a side **502**, a shoulder **504**, a neck **506** and a base plate **508** threaded into the side **502**. A projectile **510** is crimped into the neck, and is received in the firing bore **512** of the gun. The base plate **508** has central bore **514** with an annular seal **516** to pass the neck **518** of a tubular injector and nozzle assembly. This assembly includes an annular injection plate **520** having an annular seal **522** integral with the forward end of the neck and a converging/diverging nozzle **523** integral with the aft end of the neck. A frangible diaphragm **524** is cemented over the forward end of the tube and an annular priming system **526** is cemented onto the diaphragm. The priming system is similar to a torus of square cross-section, having flame passageways, loose powder, and an electrical firing system whose leads may be brought through the diaphragm and out the bore of the neck and the nozzle or through the sidewall of the case. Liquid propellant is stored in the chamber defined by the base plate **508**, the injection plate **520**, the side **502**, and the neck **518**.

This embodiment does not provide a traveling charge. Ignition of the priming system ruptures the diaphragm and moves the injector and nozzle assembly aft, which in turn provides regenerative pumping forwardly of the liquid propellant through the passageways of the injector plate.

ELEVENTH EMBODIMENT

FIG. **16** shows a recoilless gun embodiment employing a reaction or compensating mass of the type shown in U.S. Pat. No. 1,108,716. The upper half of the figure illustrates the use of a cartridge case, while the lower half illustrates the omission of a cartridge case. This embodiment does not provide a traveling charge. In its simplest form, the gun includes a firing bore **600** open at both ends. A projectile **602** with a rotating band **602a** and an injector and reaction mass assembly are secured in a tubular cartridge case **603** which is disposed in the bore **600**. The assembly comprises a solid reaction mass **604** having a peripheral seal **606** and a central bore with an annular seal **607**, in which is journaled a rod **608** to whose forward end is fixed an injection plate **610** similar to those described in the previous species, having injection bores **610a** closed by a frangible diaphragm **610b**, and having a peripheral seal **612**. A priming system **614** is fixed to the forward face of the injection plate. The priming system may comprise a sleeve molded of combustible material with flame passageways, filled with loose powder, and having an electrical firing means which may be brought out through the rod **608**. Firing is initiated by hot gases generated by the priming system in the combustion chamber defined between the projectile and the ignition plate. The liquid propellant is stored in the chamber defined between the injection plate and the reaction mass, and serves as part of the total reaction mass, so that the solid mass actually ejected out the breech of the gun is less than required by fixed, solid propellants. In the caseless embodiment, the case is omitted and the liquid propellant is injected as discussed with respect to FIG. 2B.

It is contemplated that the inventive concepts hereinabove described may be variously otherwise embodied and combined without departing from the inventive principles included and intended to be covered by the appended claims, except insofar as limited by the prior art.

What is claimed is:

1. A weapon system comprising:
- a gun having a firing bore;
- a round of ammunition disposed in said firing bore including:
- a relatively high mass projectile means longitudinally slidable in and closing the forward end of said firing bore;
- a relatively high reaction mass longitudinally slidable in and closing the aft end of said firing bore, and

having a central bore longitudinally extending therethrough;

a relatively low mass piston longitudinally slidable within and sealed to said firing bore and disposed aft of said projectile means and forward of said reaction mass, and having a central rod longitudinally extending into and sealed to said central bore of said reaction mass,

said piston having a forward face of relatively large cross-sectional area and an aft face of relatively small cross-sectional area, and a passageway communicating said aft face with said forward face, and a pressure sensitive obturating means obturating

said passageway and adapted to open said passageway upon a predetermined pressure being applied to said forward face;

said projectile means, said firing bores and said piston defining a combustion chamber;

said reaction mass, said firing bore, said piston rod and said piston defining a liquid propellant storage area.

2. A system according to claim 1 further including:

a tubular cartridge case enclosing said projectile means, said piston and said reaction mass, and serving a part of said firing bore.

* * * * *

United States Patent [19]

Ashley

[11] **4,132,149**

[45] **Jan. 2, 1979**

[54] **LIQUID PROPELLANT WEAPON SYSTEM**

[75] Inventor: **Eugene Ashley**, Burlington, Vt.

[73] Assignee: **General Electric Company**, Burlington, Vt.

[21] Appl. No.: **839,227**

[22] Filed: **Oct. 4, 1977**

Related U.S. Application Data

[62] Division of Ser. No. 707,143, Jul. 20, 1976, Pat. No. 4,069,739.

[51] **Int. Cl.**[2] **F41F 1/04; F41F 15/00**

[52] **U.S. Cl.** **89/1.704**; 89/1.705; 89/7

[58] **Field of Search** .... 89/1.7, 1.703, 1.704, 89/1.705, 1.706, 7, 8; 102/38 LP

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Primary Examiner—David H. Brown

Attorney, Agent, or Firm—Bailin L. Kuch

[57] **ABSTRACT**

A gun and ammunition system utilizing a round of ammunition which contains a supply of liquid propellant and after ignition pumps this propellant into the combustion chamber of the gun.

1 Claim, 21 Drawing Figures

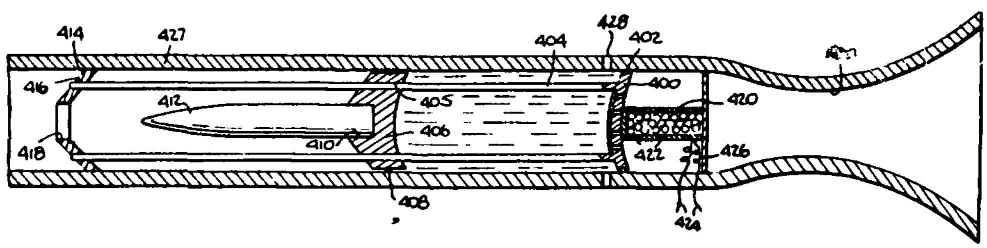


Fig. 1.

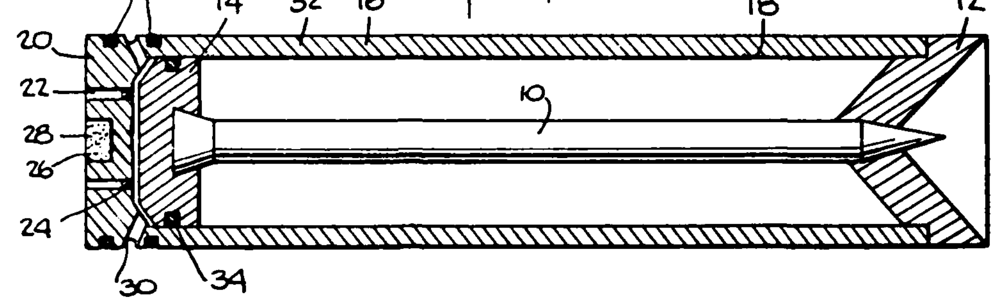


Fig. 3.

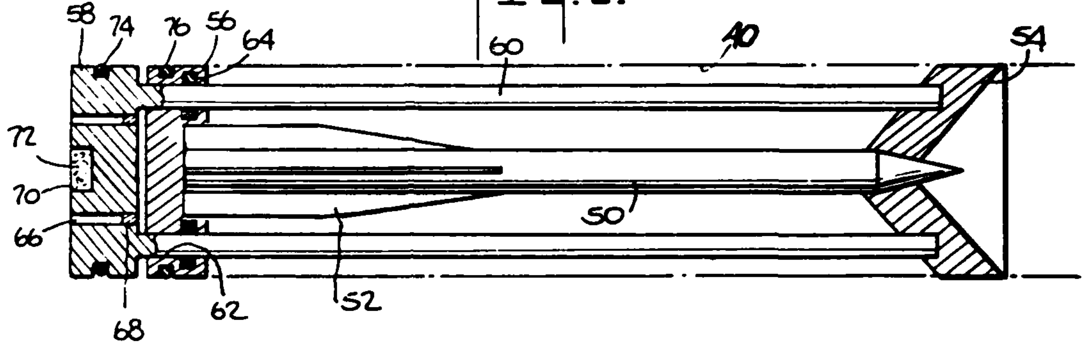
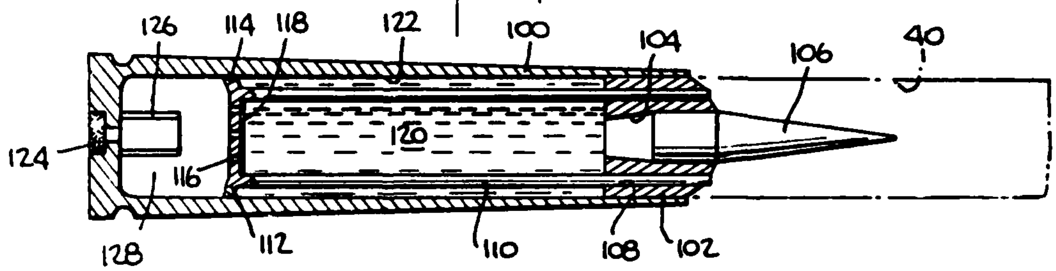


Fig. 4.



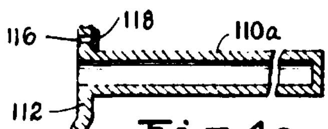


Fig. 4a

Fig. 5.

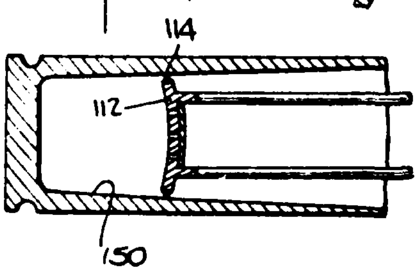
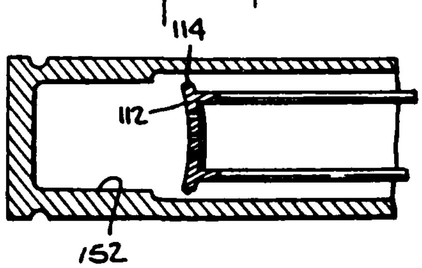


Fig. 8.



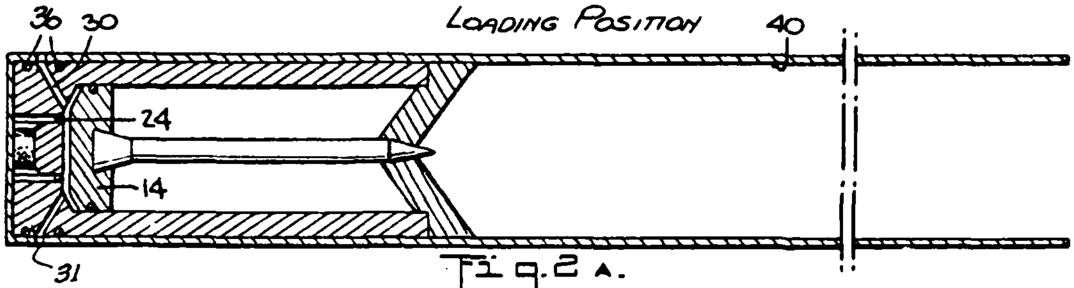


Fig. 2A.

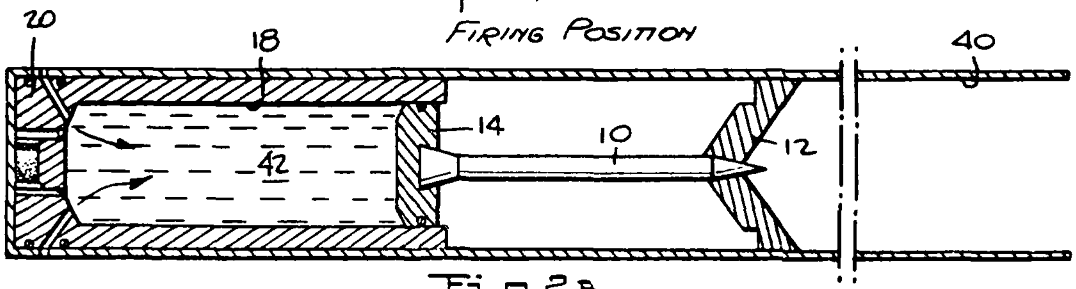


Fig. 2B.

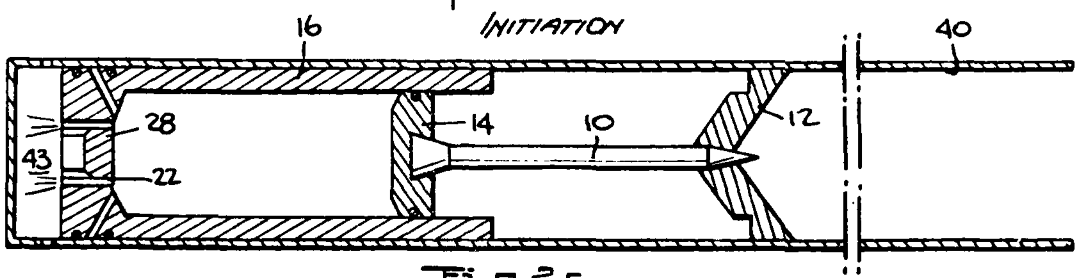


Fig. 2C.

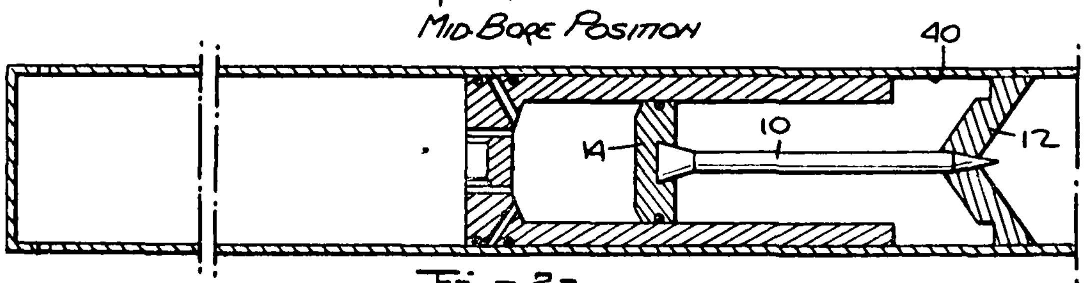


Fig. 2D.

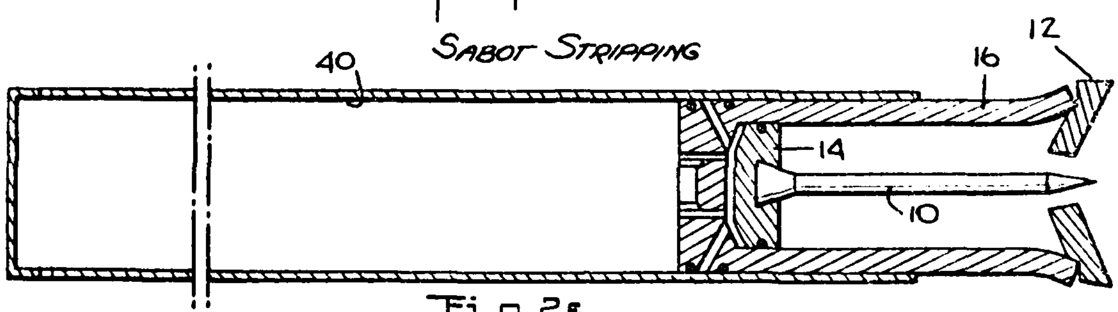


Fig. 2E.

Fig. 8.

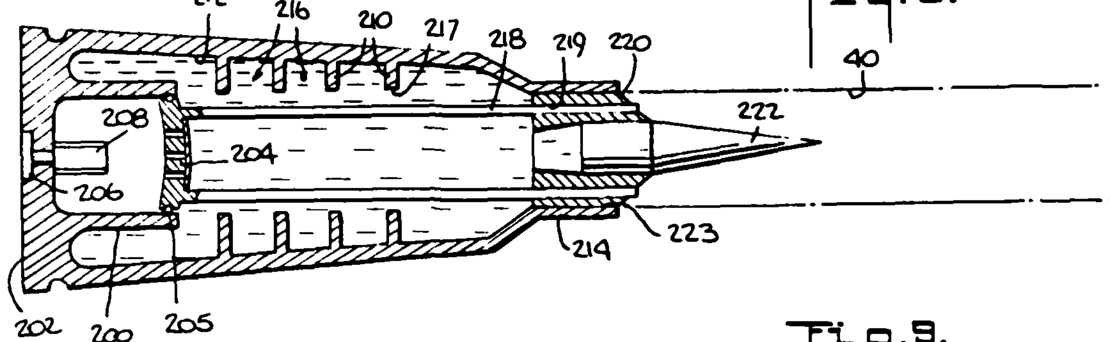


Fig. 9.

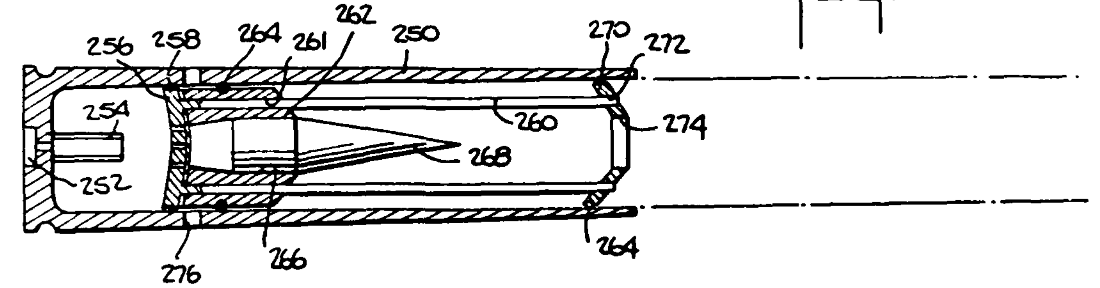


Fig. 10.

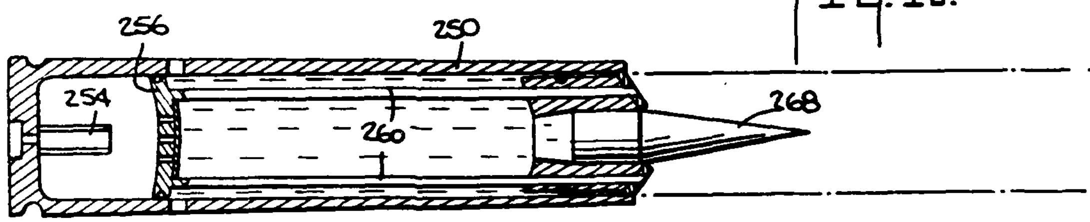
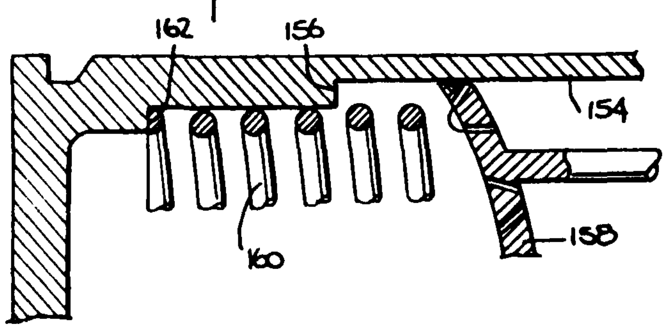


Fig. 7.



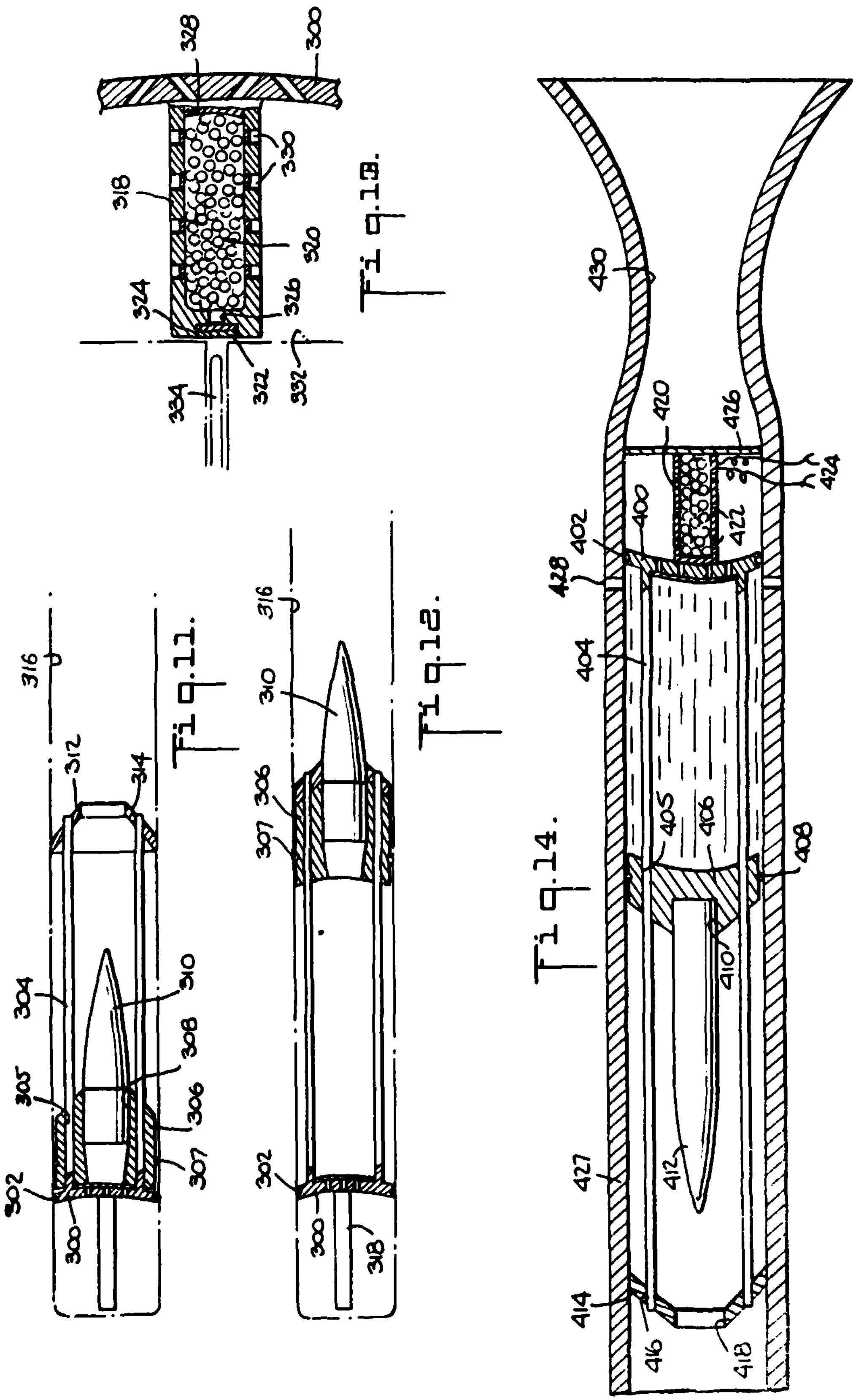


Fig.13.
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Fig.11.
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Fig.12.
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Fig.14.
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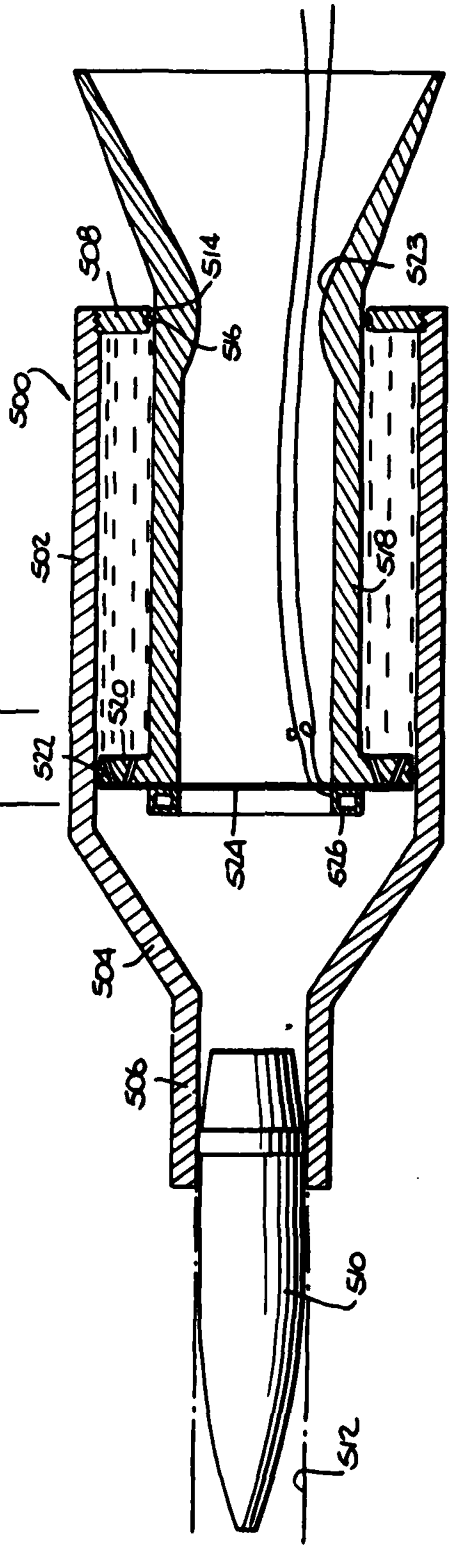
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Fig.15.

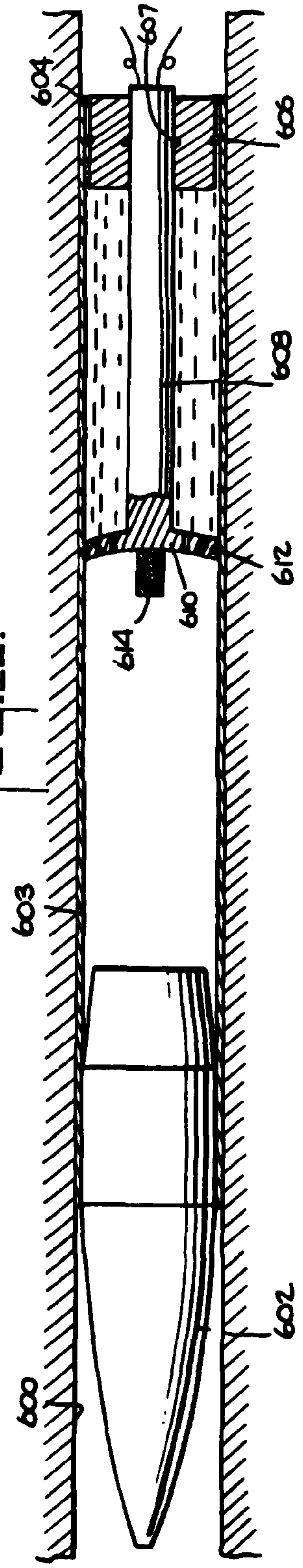
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Fig.16.

UNITED STATES PATENT OFFICE

CERTIFICATE OF CORRECTION

Patent No. 4,132,149 Dated January 2, 1979

Inventor(s) Eugene Ashley

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

Column 10, line 10 change "primary" to --priming--.

Signed and Sealed this

First Day of *May 1979*

[SEAL]

Attest:

RUTH C. MASON
Attesting Officer

DONALD W. BANNER
Commissioner of Patents and Trademarks

LIQUID PROPELLANT WEAPON SYSTEM

This application is a division of Ser. No. 707,143, filed July 20, 1976, now U.S. Pat. No. 4,069,739.

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates to weapon systems employing a liquid propellant, and particularly to such systems wherein the propellant is continuously pumped into the combustion chamber as the projectile advances along the firing bore.

2. Prior Art

Weapons systems providing traveling charge effects on projectiles, or rockets, or other related systems, are shown, for example, in U.S. Pat. Nos. 3,431,816; 3,411,403; 3,459,101; 3,496,827; 3,601,056; 3,613,499; 3,628,457; 3,648,616; 3,665,803; 3,696,749; 3,698,321; 3,712,171; and 3,728,937. In a final report for the Bureau of Ordnance, Department of the Navy, under Contract NOrd 16217 Task 1, dated Sept. 1, 1957, work was described on a propellant carrying projectile. "This projectile contained approximately 100 grams of a hydrazine, hydrazine nitrate, water monopropellant (63, 32, and 5% by weight respectively). Upon ignition of the primary bipropellant charge in the breech, regenerative injection of the bipropellants progresses in the usual manner, and the projectile is accelerated. The accelerating forces upon the projectile components are so adjusted as to produce relative motion between the projectile body and the center plunger. This motion expels the extrapped monopropellant rearward past the fragile seal disk into the hot combustion chamber gases, where it burns while the projectile is accelerated." The projectile apparently comprised a forward solid cylindrical projectile whose outer wall engaged the inner wall of the firing bore, an intermediate, longitudinally central rod journaled through a bore in the projectile, and an aft sealing disk fixed to the rod and whose periphery engaged the inner wall of the firing bore. The monopropellant was trapped between the forward cylindrical projectile and the aft disk within the firing bore. Solid primary charges were also used in lieu of liquid primary charges. A separate static sealing disk was also used in lieu of the peripheral seal on the aft sealing disk.

SUMMARY OF THE INVENTION

It is an object of this invention to provide a gun and ammunition system for launching rod-shaped projectiles at high velocity.

It is an additional object to provide such a system utilizing liquid propellants.

A feature of this invention is the provision of a gun and ammunition system utilizing a round of ammunition which contains a supply of liquid propellant and after ignition pumps this propellant into the combustion chamber of the gun.

An additional feature of this invention is the provision of a gun and ammunition system utilizing a round of ammunition carrying a relatively narrow diameter and relatively high mass projectile in a relatively wide and relatively low mass sabot, which is initially accelerated by a primary propellant charge in the combustion chamber aft of the projectile and which is subsequently accelerated by a secondary propellant charge in the round which is passed during a relatively extended period of time to the combustion chamber.

BRIEF DESCRIPTION OF THE DRAWING

These and other objects, features and advantages of this invention will be apparent from the following specification thereof taken in conjunction with the accompanying drawing in which:

FIG. 1 is a view in longitudinal cross-section of an idealized round of ammunition having a sabot and a system to regeneratively pump liquid propellant, the round is here shown in its telescoped, minimum length configuration, without liquid propellant;

FIG. 2A through E respectively illustrate, within the gun bore, the

(A) before charging with liquid propellant configuration,

(B) after charging with liquid propellant and ready for initiation of the primer configuration,

(C) shortly after initiation and commencement of injection of liquid propellant into the combustion chamber configuration,

(D) midbore configuration, and

(E) bore exiting and sabot stripping configuration,

in the sequence of operations of the round of FIG. 1;

FIG. 3 is a view in longitudinal cross-section of a second embodiment of this invention;

FIG. 4 is a view in longitudinal cross-section of a third embodiment of this invention;

FIG. 4*a* is a detail of a variant of the embodiment shown in FIG. 4;

FIGS. 5 and 6 are views in longitudinal cross-section of a fourth embodiment of this invention;

FIG. 7 is a view in longitudinal cross-section of a fifth embodiment of this invention;

FIG. 8 is a view in longitudinal cross-section of a sixth embodiment of this invention;

FIGS. 9 and 10 are views in longitudinal cross-section of a seventh embodiment of this invention;

FIGS. 11, 12 and 13 are views in longitudinal cross-section of an eighth embodiment of this invention;

FIG. 14 is a view in longitudinal cross-section of a ninth embodiment of this invention;

FIG. 15 is a view in longitudinal cross-section of a tenth embodiment of this invention; and

FIG. 16 is a view in longitudinal cross-section of an eleventh embodiment of this invention.

DESCRIPTION OF THE EMBODIMENTS

Rod shaped penetrators launched at high velocities from medium caliber guns are effective against some types of armor. Since rod penetrators are characteristically long and thin, sabot launching techniques are conventionally employed. The sabot in this case is essentially a light weight piston of diameter larger than the penetrator, and which supports the heavier penetrator. In the launching or firing process, the combustion gas acts against the area of the full diameter of the sabot, rather than against the rod alone, in accelerating the two in combination.

Liquid propellants have several desirable characteristics, such as relatively low flame temperature and ease of storage and handling. A major problem in the use of liquid propellants lies in the control of the ballistic process in the combustion chamber. Propellant can be either placed in the chamber before firing and then be ignited; or it can be metered into the chamber during the combustion process. The last mentioned, sometimes called preloading, is easier to do mechanically, but permits little control over burning after ignition. U.S. Pat

No. 3,763,739 issued to D. P. Tassie on Oct. 9, 1973, discloses a gun system of this type. The second mentioned, sometimes called force injection, permits control over the rate of burning through control over the rate of introduction of the propellant, but involves extremely high pumping pressures. Such high pressures pose stringent requirements on seals, fittings and structural components. If the energy for forced injection is to be supplied from an external source, the power requirements are very high. For example, the power required to pump 3 cubic inches of propellant across a pressure drop of 10,000 psi in 20 milli-seconds is 227 hp. This can be averaged over a larger period in an actual gun to lower the peak value, but the power requirement is still unreasonable.

An effective solution to the power requirement for pumped injection is to utilize the combustion chamber pressure itself as the source of energy for pumping. Called regenerative injection, this scheme uses a differential area piston for each propellant. The larger end of the piston is acted on by the chamber pressure, and the smaller end pressurizes the propellant to be injected. The difference in areas generates a propellant pressure sufficiently high than the chamber pressure to achieve the desired rate of injection.

FIRST EMBODIMENT

Turning now to FIG. 1, a first embodiment of the invention is shown as an idealized round of ammunition having a sabot and regenerative, liquid propellant pumping system, for use in a gun which will fill the round with propellant before firing. The penetrator 10 is here shown as a rod which upon launching will be drag stabilized. The sabot is a three piece assembly, comprising an annular nose stabilizer 12 fixed to the forward end of the penetrator, a circular pusher-plate 14 fixed to the aft end of the penetrator, and a cylindrical body 16. The body 16 has an internal bore 18 closed at its aft end 20, which bore receives the plate 14. The aft end 20 serves as an injector plate and has a plurality of longitudinal bores 22 therethrough serving as injection passageways. Each bore is obturated by a respective plug 24. An aft recess 26 receives a primary propellant charge, here shown as a solid primer 28. One or more substantially radially oriented bores 30 pass through the side wall 32 of the body into the interface between the plate 20 and the plate 14, to serve as propellant fill passageways. An annular seal 34 is provided on the periphery of the plate 14, and a pair of annular seals 36 are provided on the periphery of the body 16 straddling the fill passageways.

The plugs 24 may be embodied as relief valves, individual plugs, a burst diaphragm fixed to the forward face of the injector plate, or simply portions of the bore material not fully drilled through, all of which will shear or open at the desired pressure level.

The penetrator and sabot assembly may be preloaded with liquid propellant through the fill passageways, which are then plugged, before being placed in the gun. Alternatively, the assembly may be placed in the firing bore 40 of the gun and then loaded with propellant. The actual firing process is the same for each scheme, and loading within the gun will be discussed with respect to FIGS. 2A through 2C.

As shown in FIG. 2A, the penetrator and sabot assembly, still without its propellant charge, has been placed into the breech of a gun barrel and the breech has been closed. The fill passageways 30 are aligned with suitable fill ports 31 in the breech wall of the gun, such as are shown in U.S. Pat. No. 3,763,739, supra, which must incorporate high pressure fill valves or check valves which can withstand firing pressure. These passageways serve as means for providing liquid propellant to the round of ammunition in the firing bore.

As shown in FIG. 2B, propellant is pumped into the interface between the injector plate 20 and the pusher plate 14, progressively pushing the pusher plate forward within the bore 18 to create an injection volume 42 which receives a complete charge. Stops can be provided to halt the forward advance of the nose stabilizer, or preferably, the charge can be metered. The round is shown fully charged and ready for firing.

As shown in FIG. 2C, firing is initiated by setting off the primer, which rapidly generates a small volume of high pressure, hot gas in the space 43 aft of the injector plate which serves as the combustion chamber. This high pressure aft of the loaded round produces an immediate acceleration of the complete round. The overall force producing the acceleration, which force is equal to the chamber pressure times the chamber cross-sectional area, is exerted against the aft face of the injector plate. The penetrator and sabot assembly has a relatively high weight relative to the weight of the body 16 with a correspondingly relatively high inertia. A portion of the accelerating force is absorbed in accelerating the body 16 per se, but the remainder of the accelerating force is transmitted by the forward surface of the injector plate against the charge of liquid propellant. The resultant pressure developed in the liquid is the transmitted force divided by the liquid or injection volume cross-sectional area. When the ratio of the areas of the aft face of injector plate and the injection volume, and the body weight and the total round weights are properly predetermined, a liquid pressure will be generated which is higher than the chamber pressure as follows:

$$\frac{P_L}{P_C} = \frac{A_C}{A_L}\left(1 - \frac{W_B}{W_{TOT}}\right)$$

where P_L is liquid pressure,
P_C is chamber pressure,
A_C is chamber area,
A_L is liquid area,
W_B is body weight, and
W_{TOT} is the sum of the body, the liquid and the penetrator and sabot assembly weights.

The difference between the two pressures P_L and P_C is the driving force which can be utilized for regenerative injection.

The plugs 24 are designed to open at a predetermined difference in pressure between the interior volume and the combustion chamber. These plugs serve as a pressure sensitive obturating means. As shown in FIG. 2C, when this difference is reached, the plugs will open and propellant will flow into the chamber. The injection passageways 22 serve to atomize or break up the propellant streams through techniques similar to those used in rocket injector design. As the propellant streams initially encounter the hot primer gases they ignite, generating more hot gas. Incoming propellant continues to ignite and the process becomes self-sustaining, and generates increasing chamber pressure, which accelerates the process. The process continues until the propellant is expended. Meanwhile, the whole round is being ac-

celerated along the bore by what is in effect, a traveling charge. FIG. 2D shows the round at mid-bore length with the propellant partially expended.

As the round leaves the muzzle, the sabot fore and aft supports are stripped from the penetrator which continues on its course. FIG. 2E shows the nose stabilizer 12 acting under wind forces to open the body 16 and free the penetrator.

The entire body 16 is here shown as engaging the rifling of the bore 40 to provide spin to the entire round if a spin stabilized projectile is used. Alternatively a lesser annular portion of the body may engage the rifling.

SECOND EMBODIMENT

Frictional forces are developed between the body 16 and the interior wall of the bore 40 as the round is launched, which are a function of the materials of the body 16 and the bore 40 of the gun barrel. An alternative embodiment which minimizes such frictional forces is shown in FIG. 3.

The penetrator 50 is here shown as a rod which is stabilized by a plurality of fins 52. The sabot is a three piece assembly comprising an annular nose stabilizer 54 fixed to the forward end of the penetrator, a circular pusher-plate 56 fixed to the aft end and an injection plate 58 having a plurality of forwardly, longitudinally extending, integral rods 60. The pusher plate 56 has a like plurality of longitudinal bores 62 with respective annular seals 64 each passing a respective one of the rods 60. The injector plate 58 also has a plurality of longitudinal bores 66 therethrough each obstructed by a respective plug 68, and an aft recess 70 receiving a primary propellant charge 72, all similar to the embodiment of FIG. 1. These plugs serve as a pressure sensitive obturating means. An annular seal 74 is provided in the periphery of the injector plate, and an annular seal 76 is provided in the periphery of the pusher plate. This penetrator and sabot assembly is disposed in the gun for filling with propellant with the fill ports in the breech wall of the gun aligned with the interface between the injection plate and the pusher plate.

The use of the rods 60 upon which the pusher plate can slide permits the omission of the body structure, so that only the peripheries of the pusher plate, the injector plate and the stabilizer need contact the wall of the barrel bore 40. The liquid propellant is contained between the pusher plate, the injector plate and the wall of the barrel bore. The necessary differential in areas is provided by the total cross-sectional areas of the rods 60. The rods provide an added advantage in the sabot stripping phase of the launching cycle as they are relatively weaker and therefore easier to deflect radially outwardly than the equivalent cylindrical body 16.

Both of the embodiments described above provide the following advantages:

1. Controlled injection is achieved through regenerative pumping action;
2. The inertia of the projectile itself is the source of the pumping force;
3. The injection mechanism is incorporated into the penetrator and sabot assembly, with very little effect on the gun design;
4. A traveling charge effect is achieved;
5. The injection system and high pressure seals are used only once for each shot and are then discarded.
6. The sabot and projectile assemblies may be stored and transported as essentially inert, considering the primer to be relatively insignificant. The assemblies do not become active until the introduction of the propellant. This can be delayed until after chambering and locking in the gun.

The specification so far has dealt with idealized projectile and sabot assemblies and their launching techniques. Cartridges embodying such assemblies may be provided in at least several different configurations.

THIRD EMBODIMENT

FIG. 4 shows the simplest pre-filled cartridge case embodiment. The projectile and sabot assembly are crimped into a cartridge case 100. The assembly comprises a forward annulus 102 which serves as a pusher plate and has a central bore 104 receiving a spin stabilized projectile 106 and a plurality of bores 108 disposed in an annular row, each receiving a respective one of a like plurality of rods 110 which are respectively fixed to an injector plate 112. The injector plate has an annular seal 114 fixed to its periphery and a plurality on longitudinal injection passageways 116 which are closed by a diaphragm 118 fixed to the forward face of the plate. The liquid propellant charge 120 is contained between the annulus 102, the plate 112 and the inner wall 122 of the case 100. The bore of the case includes an external primer 124 in communication with an internal booster tube 126 disposed in the combustion chamber 128 which is defined by the base of the case, the injector plate and the interior wall of the case. Upon ignition the injector plate and its rods move forwardly relative to the annulus, rupturing the diaphragm and injecting propellant into the combustion chamber. This diaphragm serves as a pressure sensitive obturating means. The inner wall 122 of the case is cylindrical and coplanar with the inner wall 40 of the bore of the gun barrel, so that the forward annulus and the injector plate smoothly leave the case and ride along the gun bore. The forward annulus may be made up of segments to provide ready rupture and release of the projectile when the assembly leaves the gun bore.

The injector plate 112 may be made of arched cross-section for a greater strength to weight ratio.

The rods 110 may be replaced with hollow tubes 110a, as shown in FIG. 4a, which are closed at their forward ends and open at their aft ends so that the interior volume of each tube communicates with and is at the same pressure as the combustion chamber 128. This permits the use of a thin wall tube whose wall thickness become progressively thinner from front to rear; since as the length of the tube exposed forwardly of the annulus 102 into the atmosphere increases, the combustion chamber pressure decreases.

FOURTH EMBODIMENT

In the embodiments discussed above, all of the injection of the propellant into the combustion chamber takes place through the passageways of the injector plate. An enlarged "Taylor cavity" will be formed by providing a tubular cylinder of propellant liquid in the combustion chamber as said chamber is being enlarged by the forward movement of the injector plate. The "Taylor cavity" provides a liquid-gas interface for combustion. This is accomplished by providing a variable internal diameter in the case which increases towards the mouth of the case. As shown in FIG. 5, the bore 150 of the case may be tapered, or as shown in FIG. 6, the bore 152 of the case may be stepped to provide a vari-

able, increasing, orifice for the liquid propellant around the periphery of the injector plate.

FIFTH EMBODIMENT

The injector plate should be prevented from moving aft under impulse loads exerted by the liquid propellant under conditions of vigorous handling or in the event a cartridge is dropped on its base. This can be accomplished by providing stops on the displacement rods aft of their engagement with the injector plate; a step can be provided in the interior wall of the case aft of the injector plate; or the injector plate may be fastened to the interior wall of the case by a weak joint which will rupture under the firing forces. To further minimize the effects of handling loads the stops may be made resilient. As shown in FIG. 7, the interior wall **154** may be provided with a step **156** to abut the outer margin of the injector plate **158**. A helical spring **160** may be captured between an additional step **162** and the injector plate to resiliently fix the inputs plate and to permit it to move aft slightly before abuting the positive shoulder **156**.

SIXTH EMBODIMENT

In the embodiment shown in FIG. 8, a prefilled case is provided which has an interior annular wall **200** extending from the base **202** which together with the injector plate **204** and its peripheral seal **205** defines an initial combustion chamber. An external primer **206** communicates with an internal booster **208** disposed in the initial combustion chamber. A plurality of rigid, spaced apart, partitions **210** extend inwardly from the interior wall **212** of case which is tapered progressively inwardly from the base to the neck **214** to provide a series of compartments **216** of decreasing volume, each opening into a central bore **217**. As described with respect to FIG. 4, the injector plate is fixed to rods **218** which are journaled through respective bores **219** in an annulus **220** which retains the projectile **222**. The bore **223** of the neck is coplanar with the gun bore **40**. Liquid propellant is stored forward of the injection plate in the compartments **216** and in the central bore. The propellant in the central bore is injected into the combustion chamber by the injection plate as discussed with respect to FIG. 4. The propellant in each open compartment **216** tends to remain in place and to ignite as its compartment is exposed to the initial combustion chamber as the injection plate moves forward, also providing a "Taylor Cavity" effect.

SEVENTH EMBODIMENT

FIGS. 9 and 10 show a dry loaded cased cartridge embodiment, similar to the case of FIG. 4. The cartridge is provided with a case **250** having a primer **252** communicating with a booster charge **254**, and a projectile and sabot assembly. The sabot includes an injector plate **256** having a peripheral seal **258** and a plurality of longitudinally extending rods **260** fixed thereto and respectively journaled through bores **261** in an annulus **262** which has a peripheral seal **264** and an axial bore **266** receiving a projectile **268**. A stabilizing ring **270** is retained against non-firing loads aft of the mouth of the case as by cementing or crimping and has a like plurality of bores **272** journaling said rods **260** and an axial bore **274** adapted to pass the projectile. A plurality of radial bores **276** are disposed through the case in an annular row to serve as propellant filling passageways. In the stored configuration, as shown in FIG. 9, the annulus **262** is nested aft, close to the injector plate, without any liquid propellant, and the seals **258** and **264** straddling the row of bores **276**. After the case has been loaded into the gun and the gun breech has been locked, the liquid propellant charge is pumped through aligned ports in wall of the breech of the gun as described with respect to FIG. 2B. The injector plate is prevented from aftward movement by suitable means, such as the stops described with respect to FIG. 7. As the liquid propellant charge is pumped into the interface between the injector plate and the annulus, it forces the annulus forward until it is stopped by the stabilizing ring, which provides an automatic metering device for the filling operation.

Both pre-loaded and dry-loaded cased cartridges share the following advantages:

1. Sealing of the breech is provided by the case.
2. The priming system is conveniently provided for each round.
3. A misfired round can be completely extracted by extracting the case.

The dry-loaded cartridge has the additional following advantages for shipping and handling:

1. The projectile is telescoped within the case for shipping and for loading into the gun. This minimizes the length of the parts to be handled.
2. The cartridge is relatively safe. In the absence of propellant, the primer and booster are the only combustible components present.
3. The propellant is loaded separately through control valves and piping. This can be controlled remotely if necessary.
4. The breech is closed before the propellant is charged into the cartridge, providing additional safety.

EIGHTH EMBODIMENT

FIGS. 11 and 12 show a dry-loaded uncased cartridge, which is loaded, locked, filled and fired in a manner similar to the cased cartridge of FIGS. 9 and 10. The sabot and projectile assembly comprises an injector plate **300** having a peripheral seal **302** and a plurality of longitudinally extending rods **304** fixed thereto and respectively journaled through bores **305** in an annulus **306** which has a peripheral seal **307** and an axial bore **308** receiving a projectile **310**. A stabilizing ring **312** has a like plurality of bores **314** journaling said rods **304** and an axial bore **316** adapted to pass the projectile. As shown in FIG. 13, a primer and booster assembly comprises a sleeve **318** which cemented to the aft face of the injector plate **300**. The sleeve is molded of solid propellant, of sufficient strength to provide a small combustion chamber **320** initially, but which will ultimately burn. A combustible primer **322** is fixed in a cup **324** in the exterior of the base of the sleeve and which communicates by a passageway **326** with the combustion chamber **320**. The forward end of the sleeve is closed with a plug **328** which may be cemented. Radially extending flame passageways **330** are provided through the walls of the sleeve. These passageways are initially closed, as by plugs, being only partially formed through, or covered by a diaphragm. Loose powder is disposed in the combustion chamber.

The length of the primer and booster assembly is made equal to the length of the combustion chamber of the gun. When the cartridge is chambered and the breech is locked, the primer **322** is adjacent the face **332** of the breech block, and may be ignited by a conventional percussion firing pin **334**, or electrical firing means. The primer ignites the loose powder immedi-

ately, generating hot gases which rupture the flame passageway closures and pass into the combustion chamber. The molded combustible sleeve burns more slowly than the loose powder, but eventually all is consumed. The hot gas initiates the regenerative liquid propellant injection process as described previously.

The dry-loaded caseless cartridges have the following advantages:

1. The system is completely combustible. The gun chamber is completely empty after each shot.

2. The primary system is an integral part of the cartridge as supplied to the gun.

3. The primary system may be fabricated using conventional caseless ammunition technology.

NINTH EMBODIMENT

FIG. 14 shows a recoiless gun embodiment of a caseless cartridge similar to that shown at FIG. 12. The sabot and projectile assembly comprises an injector plate **400** having a peripheral seal **402** and a plurality of longitudinally extending rods **404** fixed thereto and respectively journaled through bores **405** in an annulus **406** which has a peripheral seal **408** and an axial bore **410** receiving a projectile **412**. A stabilizing ring **414** has a like plurality of bores **416** journaling said rods **404** and an axial bore **418** adapted to pass the projectile. A priming system comprising a sleeve **420** which may be molded of solid propellant is cemented to the aft face of the injector plate **400**. The sleeve has radially extending flame passageways **422** which are initially closed and contains loose powder which may be ignited by an electrical firing system **424**. A frangible diaphragm **426** is cemented to the aft end of the sleeve. The initial combustion chamber is provided within the sleeve, and the subsequent combustion chamber is defined between the injection plate and the diaphragm. The diaphragm is adapted to burst at a pressure which is high enough to insure that initiating combustion has been achieved.

The gun **427** includes suitable ports **428** to pass liquid propellant to the interface between the injection plate **400** and the annulus **406**. The gun also includes a converging/diverging nozzle **430** in lieu of the conventional closed breech. This nozzle may be of the type shown, for example, in U.S. Pat. Nos. 2,444,949, 2,696,760, 2,790,353 and 3,610,093. **The nozzle provides an expansion chamber and a venturi orifice therein to allow a sufficient amount of the combustion gases to expand and escape rearwardly, thereby stabilizing the gun against recoil. The nozzle may be made separable from the breech to permit loading of the cartridge. FIG. 14 shows the annulus 406 midway in its forward advance during the loading with liquid propellant.**

TENTH EMBODIMENT

FIG. 15 shows a recoiless gun embodiment of a cased, preloaded cartridge. The cartridge includes a case **500** having a side **502**, a shoulder **504**, a neck **506** and a base plate **508** threaded into the side **502**. A projectile **510** is crimped into the neck, and is received in the firing bore **512** of the gun. The base plate **508** has central bore **514** with an annular seal **516** to pass the neck **518** of a tubular injector and nozzle assembly. This assembly includes an annular injection plate **520** having an annular seal **522** integral with the forward end of the neck and a converging/diverging nozzle **523** integral with the aft end of the neck. A frangible diaphragm **524** is cemented over the forward end of the tube and an annular priming system **526** is cemented onto the diaphragm. The priming system is similar to a torus of square cross-section, having flame passageways, loose powder, and an electrical firing system whose leads may be brought through the diaphragm and out the bore of the neck and the nozzle or through the sidewall of the case. Liquid propellant is stored in the chamber defined by the base plate **508**, the injection plate **520**, the side **502**, and the neck **518**.

This embodiment does not provide a traveling charge. Ignition of the primary system ruptures the diaphragm and moves the injector and nozzle assembly aft, which in turn provides regenerative pumping forwardly of the liquid propellant through the passageways of the injector plate.

ELEVENTH EMBODIMENT

FIG. 16 shows a recoilless gun embodiment of a cased cartridge employing a reaction or compensating mass of the type shown in U.S. Pat. No. 1,108,716. This embodiment does not provide a traveling charge. In its simplest form, the gun includes a firing bore **600** open at both ends. A projectile **602** and an injector and reaction mass assembly are secured in a tubular cartridge case **603** which is disposed in the bore **600**. The assembly comprises a solid reaction mass **604** having a peripheral seal **606** and a central bore with an annular seal **607**, in which is journaled a rod **608** to whose forward end is fixed an injection plate **610** having a peripheral seal **612**. A priming system **614** is fixed to the forward face of the injection plate. The priming system may comprise a sleeve molded of combustible material with flame passageways, filled with loose powder, and having an electrical firing means which may be brought out through the rod **608**. Firing is initiated by hot gases generated by the priming system in the combustion chamber defined between the projectile and the ignition plate. The liquid propellant is stored in the chamber defined between the injection plate and the reaction mass, and serves as part of the total reaction mass, so that the solid mass actually ejected out the breech of the gun is less than required by fixed, solid propellants. In a caseless embodiment, not shown, the case is omitted and the liquid propellant is injected as discussed with respect to FIG. 2B.

It is contemplated that the inventive concepts hereinabove described may be variously otherwise embodied and combined without departing from the inventive principles included and intended to be covered by the appended claims, except insofar as limited by the prior art.

What is claimed is:

1. A weapon system comprising:
a gun; and
a round of ammunition;
said gun having a firing bore closed by a breech face;
said round of ammunition disposed in said firing bore adjacent said breech face;
said round of ammunition including:
a relatively high mass projectile means having an aft face; and
a relatively low mass piston, longitudinally spaced from said projectile, having an aft face of relatively large cross-sectional area spaced from said breech face and a forward face of relatively small cross-sectional area, a passageway therethrough, communicating between said aft and forward faces of said piston, and a pressure sensitive obturating means, obturating said passageway and adapted to open said passageway upon

a predetermined pressure being provided on said forward face; and

said firing bore has an extension aft of said breech face formed as a converging/diverging nozzle, and said breech face is provided by a burstable diaphragm disposed in said firing bore aft of said round and forward of said nozzle.

* * * * *

United States Patent [19]
Tassie

[11] 4,193,335
[45] Mar. 18, 1980

[54] GUN MISFIRE CONTROL

[75] Inventor: Douglas P. Tassie, St. George, Vt.

[73] Assignee: General Electric Company, Burlington, Vt.

[21] Appl. No.: 935,050

[22] Filed: Aug. 18, 1978

Related U.S. Application Data

[63] Continuation of Ser. No. 778,769, Mar. 17, 1977, abandoned.

[51] Int. Cl.[2] F41D 7/02
[52] U.S. Cl. 89/7; 89/11
[58] Field of Search 89/7, 9, 11, 181

[56] References Cited

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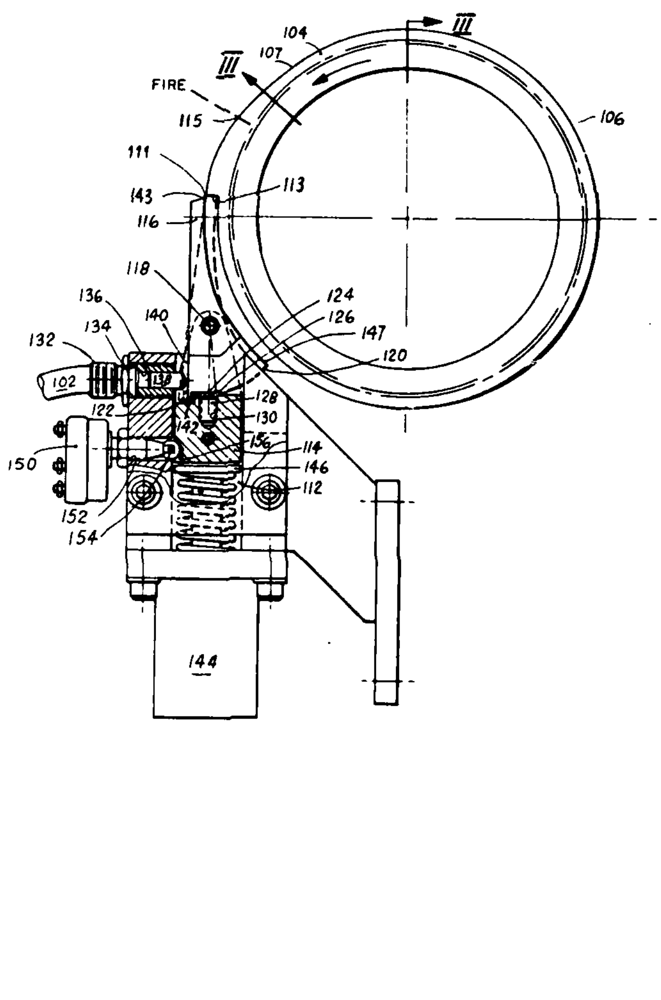
Primary Examiner—Stephen C. Bentley
Attorney, Agent, or Firm—Bailin L. Kuch

[57] ABSTRACT

A mechanism is provided to detect the occurrence of a misfire in an automatic gun and for thereupon halting, prior to the unlocking of the gun, the further operation of the gun; which is particularly adapted to liquid propellant guns having a rotating drum.

11 Claims, 4 Drawing Figures



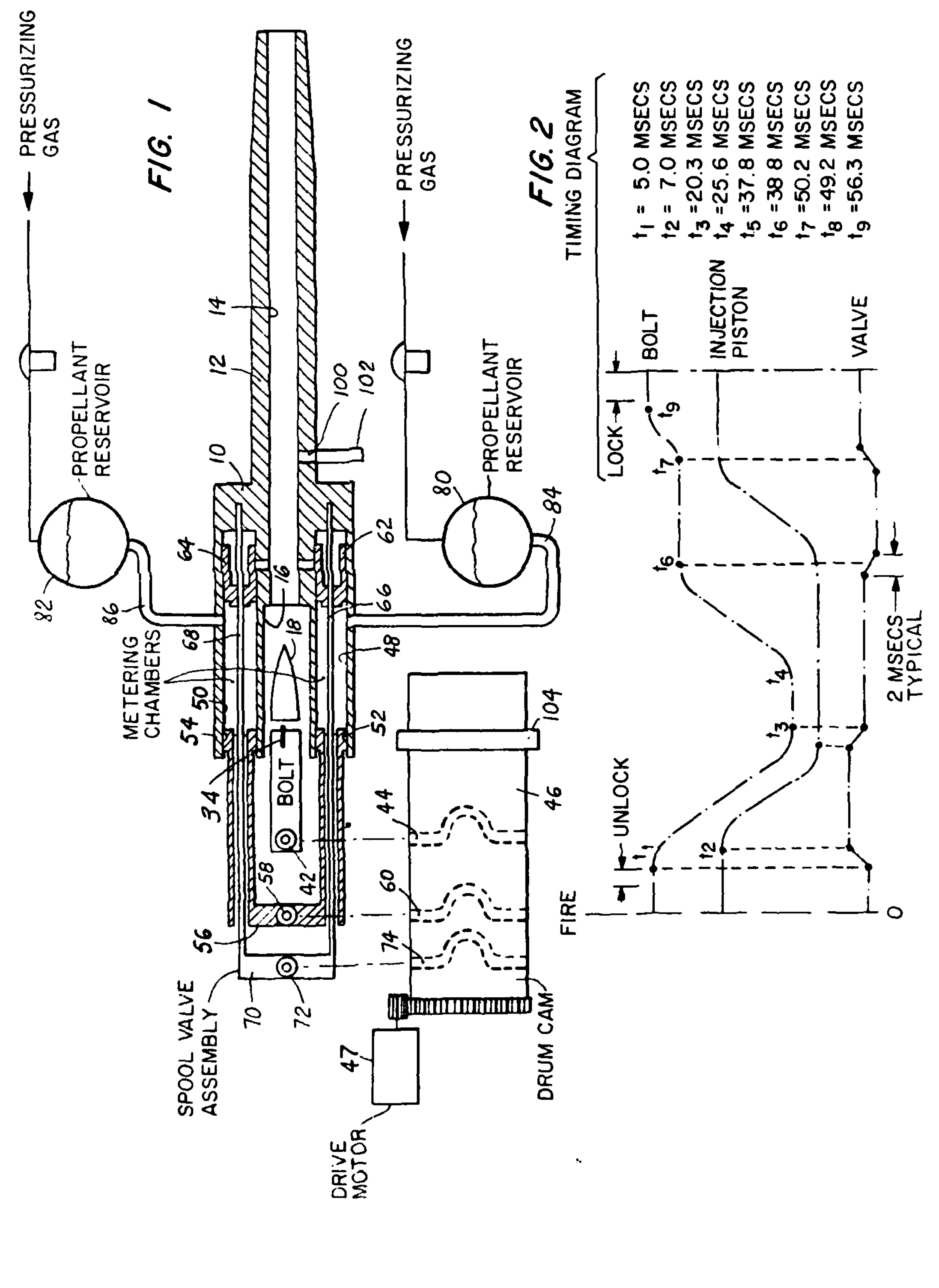


FIG. 1
PRESSURIZING GAS
PROPELLANT RESERVOIR
METERING CHAMBERS
BOLT
SPOOL VALVE ASSEMBLY
DRUM CAM
DRIVE MOTOR
FIG. 2
TIMING DIAGRAM
t_1 = 5.0 MSECS
t_2 = 7.0 MSECS
t_3 =20.3 MSECS
t_4 =25.6 MSECS
t_5 =37.8 MSECS
t_6 =38 8 MSECS
t_7 =50.2 MSECS
t_8 =49.2 MSECS
t_9 =56.3 MSECS
LOCK
UNLOCK
FIRE
INJECTION PISTON
VALVE
2 MSECS TYPICAL

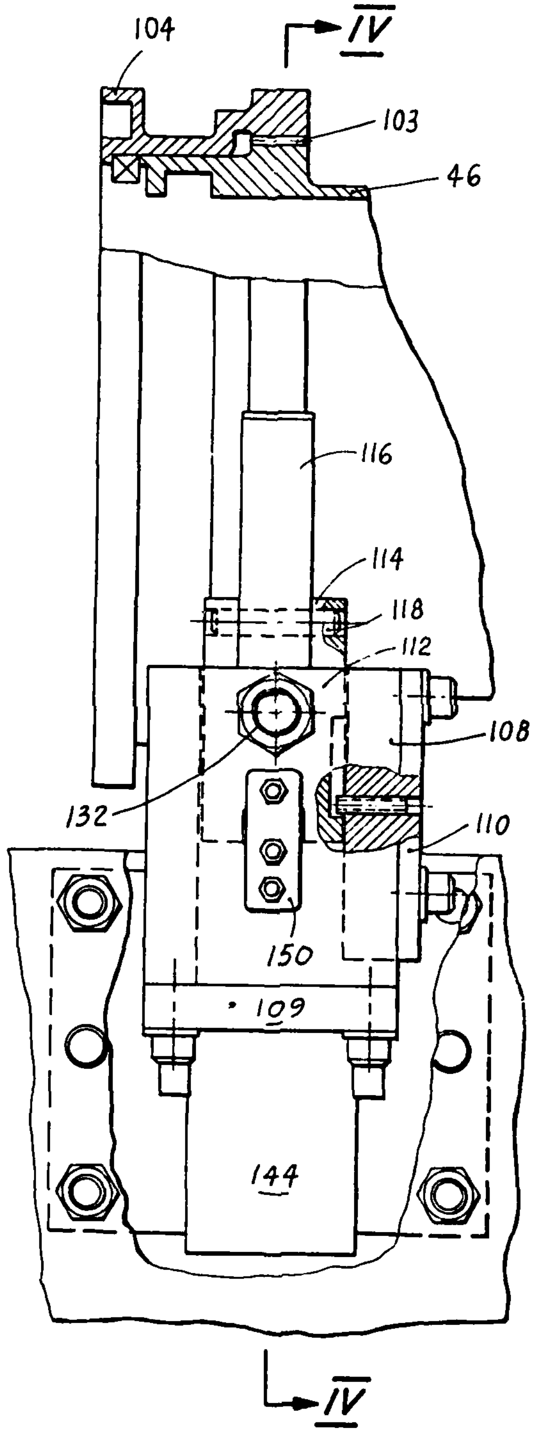
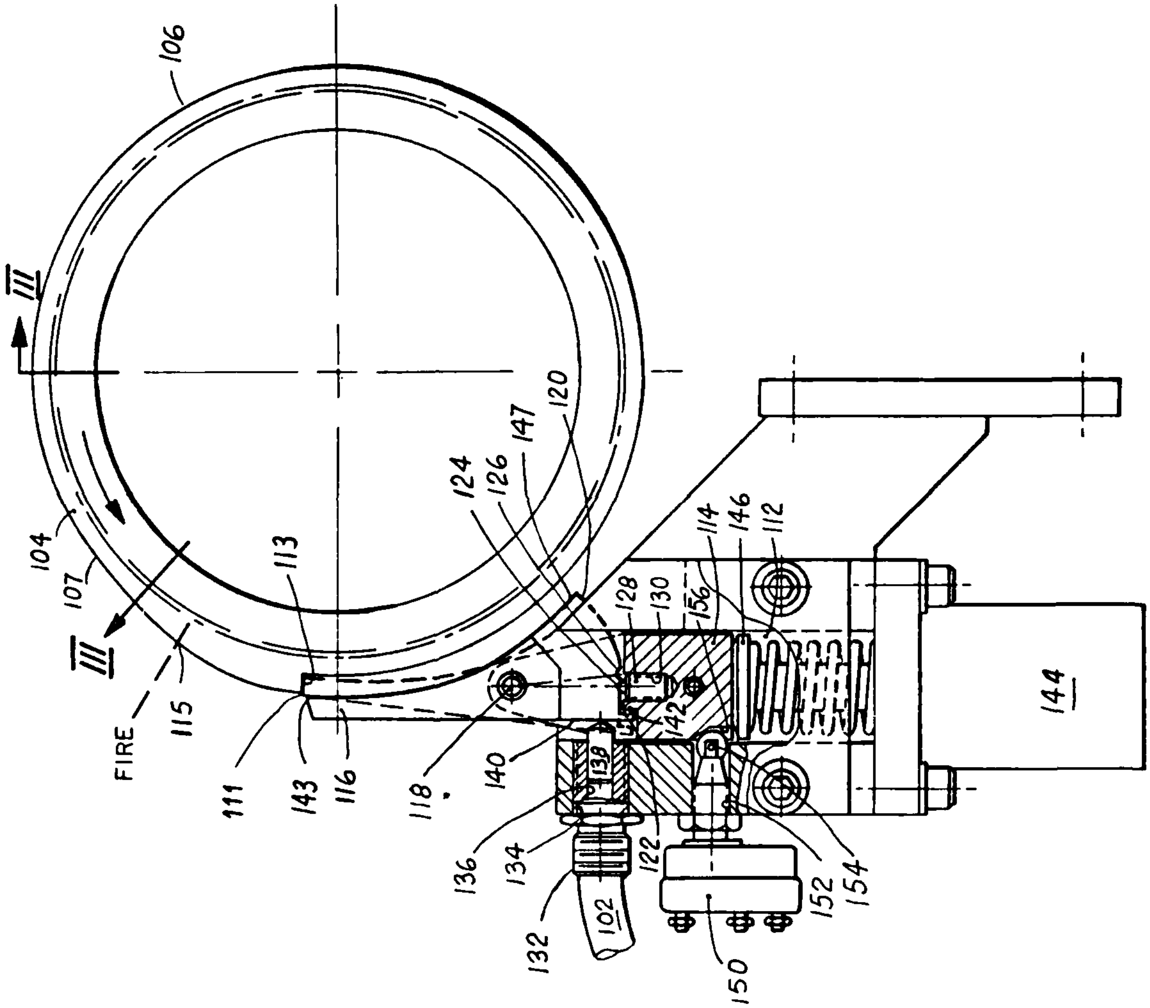


FIG. 3


106
III
III
104
107
FIRE
115
113
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143
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118
124
126
147
120
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130
156
114
146
112
140
138
142
136
134
122
132
102
150
152
154
144

FIG. 4

GUN MISFIRE CONTROL

This application is a continuation of Ser. No. 778,769 filed Mar. 17, 1977, now abandoned.

The U.S. Government has rights in this invention pursuant to Contract No. N00123-75-C-0670 awarded by the Department of Defense.

BACKGROUND OF THE INVENTION

1. Field of the Invention.

This invention relates to a mechanism for detecting the occurrence of a misfire in an automatic gun and for thereupon halting the further operation of such gun.

2. Prior Art

In a conventional, single barrel, selfpowered, automatic gun firing cased ammunition, when a misfire occurs, the gun stops in its operating cycle, sometimes after having unlocked the bolt. If the misfire is a true dud, the operator usually merely cycles the gun to eject the dud and to chamber and lock a fresh round. If the misfire is a hangfire and if the bolt is unlocked when the hangfire occurs, it may cause a wrecked gun.

In a conventional, single barrel, externally powered, automatic gun firing cased ammunition, when a misfire occurs, the gun continues its operating cycle. If the misfire is a true dud, the gun will eject the dud, and chamber and lock a fresh round. If the misfire is a hangfire and if the bolt is unlocked when the hangfire occurs, it will cause a wrecked gun.

Similar problems occur in multibarreled guns, and in guns firing caseless ammunition, whether using solid or liquid propellant.

SUMMARY OF THE INVENTION

It is an object of this invention to provide a mechanism to detect the occurrence of a misfire in an automatic gun and for thereupon positively halting, prior to the unlocking of the gun, the further operation of the gun.

It is a further object to provide such a mechanism which is particularly adapted to liquid propellant guns having a rotating drum.

A feature of this invention is the provision of a cam which is coupled to the gun and which rotates in synchronism with the operating cycle of the gun, pressure sensitive means for detecting the firing of a round and in the absence of such firing, for positively halting rotation of the cam after the time for firing and before the time for unlocking the gun bolt.

BRIEF DESCRIPTION OF THE DRAWING

These and other objects, advantages and features of the invention will be apparent from the following specifications thereof taken in conjunction with the accompanying drawing in which:

FIG. 1 is schematic of an exemplary liquid propellant gun system as disclosed in U.S. Pat. No. 3,763,739;

FIG. 2 is a timing diagram of the gun of FIG. 1;

FIG. 3 is a side view in cross-section taken along the plane III—III of FIG. 4; and

FIG. 4 is an end view in cross-section of an embodiment of this invention in combination with the gun of FIG. 1 taken along plane IV—IV of FIG. 3.

DESCRIPTION OF THE INVENTION

The gun system shown in FIG. 1 is disclosed in greater detail in U.S. Pat. No. 3,763,739, issued to D. P. Tassie on Oct. 9, 1973. The gun includes a receiver **10**, in which is fixed a barrel **12** having a bore **14**. The aft end of the bore is chambered at **16** to provide a combustion chamber and to receive a projectile **18** having an O-ring seal and a rotating band. The receiver includes a bolt body having a bolt head having a central bore in which an electrode **34** is fixed in a dielectric sleeve, and appropriate seal rings. The bolt has a transversely projecting roller **42** which rides in a cam slot **44** in a drum cam **46**, and which cam is driven by a motor **47**. The receiver includes two additional longitudinal bores **48** and **50** in which two pistons **52** and **54** respectively slide. The two pistons are coupled aft by a yoke **56** which has a transversely projecting roller **58** which rides in a cam slot **60** in the cam **46**. Two spools **62** and **64** respectively slide in the forward portions of the bores **48** and **50**. The spools are respectively fixed to two rods **66** and **68** which are coupled aft by a yoke **70** which has a transversely projecting roller **72** which rides in a cam slot **74** in the cam **46**. Two propellant reservoirs **80** and **82** are pressurized by suitabl supplies of gas and are respectively coupled by conduits **84** and **86** to the bores **48** and **50**. The supply of electrical energy to the electrode for the purpose of igniting the liquid propellant may also be controlled by the drum cam **46** by means of a suitable cam and switch, not shown.

A gas port **100** is provided in the gun barrel **12** forward of the forcing cone and the start of the rifling. Combustion gas pressure is available at this port **100** only if the round has fired and its projectile has moved forward past this port. A conduit **102** is fitted to this port.

A stop cam **104** is fixed to the drum cam **46**. The stop cam is substantially annular and may be fixed to the drum cam by an annular row of splines **103**.

A stop mechanism **108** is fixed to the gun housing for cooperation with the stop cam **104**. The mechanism includes a housing **109**, which as a side cover **110**, and provides a rectangular cavity **112** open at the top, in which is slid a bifurcated yoke **114**. A pawl stop **116** is pivotably mounted between the bifurcations by a dowel pin **118**. The base **120** of the pawl stop has a projecting detent **122** and two detent recesses **124** and **126**. A spring loaded ball plunger **128** is disposed in a bore **130** in the base of the yoke and is adapted to engage one or the other of recesses **124** and **126**. The conduit **102** terminates in a fitting **132** which is threaded into a bore **134** in the housing. The fitting has a longitudinal bore **136** in which is disposed a piston **138**. The distal end of the piston **138** abuts the lower end **140** of the pawl stop **116**. Thus gas pressure in the conduit **102** will project the piston **138** to swing the pawl stop counter-clockwise (as seen in FIG. 4) until the detent **122** abuts a shoulder **142** on the yoke, and the ball plunger **128** enters the detent recess **124** to hold the pawl stop in that position. A shock block **144** is fixed to the base of the housing and has a spring load plunger **146** fixed to a hydraulic damper and supports the yoke **114** in the cavity **112**. A microswitch **150** is threaded into a bore **152** in the housing and has a spring loaded activator with a cam follower **154** extending into the cavity and adapted to abut a cam surface **156** on the base of the yoke. Should the yoke slide down in the cavity against the urging of the plunger **146**, the ramp portion of the cam surface **156** will ride against the cam follower **154** and actuate the microswitch **150**.

The drum cam **104** has a peripheral cam surface **106** which is of constant radius, except at a point **107** whereat it starts to progressively rise until a high point **111** whereat it abruptly falls back to the constant radius, providing a radial shoulder **113**. The drum cam **104** rotates counter-clockwise (as seen in FIG. **4**).

In normal operation, the cam rotates counter-clockwise, and shortly after the high point **111** passes its angular orientation **115** at which time the gun fires, gas under pressure exits the gun barrel bore **100** to enter the conduit **102** to project the piston **138**, to rotate the pawl stop **116** counter-clockwise so that the tip **143** of the pawl stop is swung out of the path of the shoulder **113**, until the detent **122** engages the shoulder **142** and the ball plunger **128** engages the recess **124**. As the cam continues its rotation, the high point **111** strikes the surface **147** of the pawl stop **116** and swings the pawl stop clockwise until the tip **143** of the pawl stop rides on the constant radius surface of the cam and the ball plunger **128** engages the recess **126**. The cycle of operation just described is repeated for each gun cycle.

However, in the event of a misfire, no gas pressure is provided in the conduit **102** and the plunger is not projected to clear the pawl stop. The tip **143** of the pawl stop engages the shoulder **113** to halt further rotation of the cam. Deceleration is provided by shoulder **113** driving the pawl stop **116** and the yoke **114** against the urging of the spring loaded plunger **146** of the shock block. As the yoke descends, it actuates the micro-switch to cut off power to the drive motor. The gun cycle is thus halted before the unlocking of the gun bolt occurs.

What is claimed is:

1. An automatic gun having an operating cycle and comprising:

a gun barrel having a gun bore and a projectile receiving chamber;

first means for closing and locking said chamber;

second means operating in synchronism with and controlling the operating cycle of said gun, including a first cam rotating in synchronism with the operating cycle of said gun;

third means coupled to said gun barrel and to said second means for detecting the firing out of a projectile from said chamber, and in the absence of said firing, for positively halting operation of said second means after the time for firing and before the time for unlocking said chamber by said first means, including detent means having a first position whereat it clears said first cam, and a second position whereat it halts said first cam at a first predetermined angular orientation of said first cam; and

said first cam including additional means to cyclically set said detent means to said second position at a second predetermined orientation of said first cam.

2. A gun according to claim **1** wherein:

said third means includes

detector means coupled to and between said gun bore and said detent means for detecting the presence of combustion gas in said gun bore and for thereup setting said detent means to said first position thereof.

3. A gun according to claim **2** wherein:

said additional means of said first cam functions each gun operating cycle before the time for firing; and said detector means functions, if at all, after the time for firing and before the time for unlocking said chamber.

4. A gun according to claim **3** wherein:

said detector means includes a conduit coupled into said gun bore forward of said chamber to convey combustion gas under pressure to said detent means.

5. A gun according to claim **4** wherein:

said first cam includes a rotating shoulder; and

said detent means includes a pivoting dog adapted to be swung into and out of the orbit of said shoulder.

6. An automatic gun having an operating cycle including load, lock, fire and unlock operations in sequence;

a gun barrel having a gun bore and a projectile and propellant receiving chamber;

first means for closing and locking said chamber;

second means for firing propellant disposed within said chamber;

third means for operating said first means to close and lock said chamber, for subsequently operating said second means for firing any propellant disposed within said chamber, and for yet subsequently operating said first means to unlock and open said chamber, including a first cam rotating in synchronism with the operating cycle of said gun and controlling said operating cycle;

fourth means coupled to said gun barrel and to said third means for detecting the firing of propellant within said chamber and in the absence of such detection, for positively halting the operation of said third means after the time for firing by said second means and before the time for unlocking by said first means, including detent means having a first position whereat it clears said first cam, and a second position whereat it positively halts said first cam at a first predetermined angular orientation of said first cam;

and said first cam including additional means to cyclically set said detent means to said second position at a second predetermined orientation of said first cam.

7. A gun according to claim **6** wherein:

said fourth means includes

detector means coupled to and between said gun bore and said detent means for detecting the presence of combustion gas in said gun bore and for thereup setting said detent means to said first position thereof.

8. A gun according to claim **7** wherein:

said additional means of said first cam functions each gun operating cycle before the time for firing; and

said detector means functions, if at all, after the time for firing and before the time for unlocking said chamber.

9. A gun according to claim **8** wherein:

said detector means includes a conduit coupled into said gun bore forward of said chamber to convey combustion gas under pressure to said detent means.

10. A gun according to claim **9** wherein:

said first cam includes a rotating shoulder; and

said detent means includes a pivoting dog adapted to be swung into and out of the orbit of said shoulder.

11. An automatic gun having an operating cycle including load, lock, fire and unlock operations in sequence;

a gun barrel having a gun bore and a projectile and propellant receiving chamber;

first means for closing and locking said chamber;

second means for firing propellant disposed within said chamber and for generating gas pressure in said chamber;

third means for operating said first means to close and lock said chamber, for subsequently operating said second means for firing any propellant disposed within said chamber, and for yet subsequently operating said first means to unlock and open said chamber;

fourth means coupled to said gun barrel and to said third means for detecting the generation of gas pressure in said chamber and in the absence of such detection, for positively halting the operation of said third means after the time for firing by said second means and before the time for unlocking by said first means;

said third means including a first cam rotating in synchronism with the operating cycle of said gun and controlling said operating cycle; and

said fourth means including detent means having a first position whereat it clears said first cam, and a second position whereat it positively halts said first cam at a first predetermined angular orientation of said first cam; and

said first cam means including additional means to cyclically set said detent means to said second position at a second predetermined orientation of said first cam.

* * * * *

United States Patent [19]

Tassie et al.

[11] **4,215,620**

[45] **Aug. 5, 1980**

[54] **IGNITION DEVICE**

[75] Inventors: **Douglas P. Tassie,** St. George, Vt.; **Robert A. Pustell,** Andover, Mass.

[73] Assignee: **General Electric Company,** Burlington, Vt.

[21] Appl. No.: **849,736**

[22] Filed: **Nov. 9, 1977**

Related U.S. Application Data

[62] Division of Ser. No. 723,367, Sep. 15, 1976, Pat. No. 4,085,653.

[51] **Int. Cl.**^{2} **F42B 33/10**

[52] **U.S. Cl.** .... **86/1 R;** 102/46; 174/102 P; 89/7

[58] **Field of Search** .... 174/102 P, 118; 89/7; 102/38 R, 46; 86/1 R

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3,056,576	10/1962	Haefner	102/46 X
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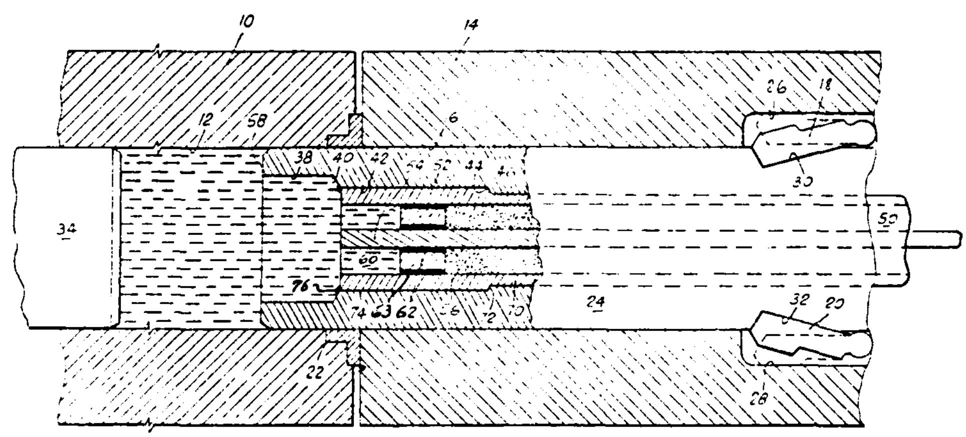
3,754,506	8/1973	Parker	102/46
3,763,739	10/1973	Tassie	89/7

Primary Examiner—Harold J. Tudor
Attorney, Agent, or Firm—Bailin L. Kuch

[57] **ABSTRACT**

An igniter assembly for use in liquid propellant guns comprises an outer tubular conductor and an inner conductor spaced apart by a volume of tightly packed, irregular granules of an insulating material, such as a mineral powder. The outer conductor is supported in a longitudinal bore of a gun bolt.

7 Claims, 1 Drawing Figure



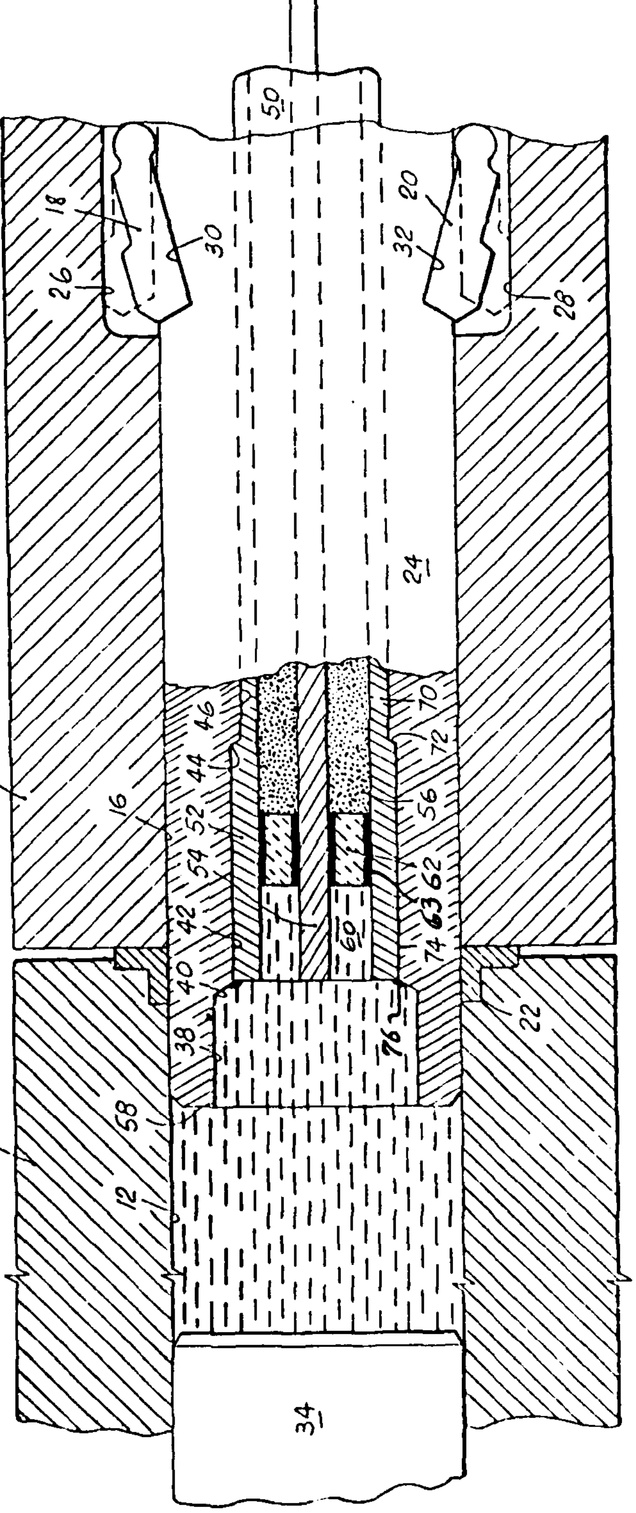

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FIG. 1.

IGNITION DEVICE

RELATED PATENTS

This application is a division of Ser. No. 723,367 filed Sept. 15, 1976, and issued on Apr. 25, 1978 as U.S. Pat. No. 4,085,653.

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates to ignition devices for use in a high mechanical shock environment, such as the ignition of liquid propellant in a gun, or the ignition of fuel in a jet engine.

2. Prior Art

The use of an igniter, per se, in a liquid propellant gun is shown by Broussard in U.S. Pat. No. 2,088,503, issued July 27, 1937; Rost in U.S. Pat. No. 2,129,875, issued Sept. 13, 1938; Barbieri et al in U.S. Pat. No. 3,326,084, issued June 20, 1967; Myers in U.S. Pat. No. 3,673,917, issued July 4, 1972; Nelson et al in U.S. Pat. No. 3,728,937, issued Apr. 24, 1973; Tassie in U.S. Pat. No. 3,763,739, issued Oct. 9, 1973; and Broxholm et al in U.S. Pat. No. 3,949,642, issued Apr. 13, 1976. Of these, Tassie and Broxholm et al show the igniter coaxially mounted in the gun bolt, as does Mitchell in U.S. Pat. No. 3,608,492, issued Sept 28, 1971 in a gun firing caseless ammunition.

The conventional igniter is an assembly of solid, rigid parts. The main insulator is usually a hard, high-fire ceramic, which is then combined with seals and fitted inside a strong, outer case which also serves as the outer conductor or electrode. The center electrode together with seals is fitted through a longitudinal bore in the main insulator. In a high mechanical shock environment, i.e., high pressure pounding, the assembly deteriorates; the seals deteriorate; the ceramic cracks, or one part slips with respect to another. Such slippage causes more breakage; the seal fails, combustion gas leaks, and eventually the igniter even fails to spark.

Accordingly, it is an object of this invention to provide an igniter which is unaffected by a high mechanical shock environment.

An additional object of this invention is to provide a gun bolt and igniter assembly which is effective in a liquid propellant gun.

Another object of this invention is to provide a process for the manufacture of such an igniter.

A feature of this invention is the provision of an igniter assembly comprising an outer tubular conductor and an inner conductor spaced apart by a volume of tightly packed, irregular granules of an insulating material, such as a mineral powder. The outer conductor is supported in a longitudinal bore of a gun bolt.

BRIEF DESCRIPTION OF THE DRAWING

These and other objects, advantages and features of the invention will be apparent from the following specification thereof taken in conjunction with the accompanying drawing in which:

FIG. 1 is a top plan view, in longitudinal cross-section through the gun bolt, of a liquid propellant gun utilizing an ignition device embodying this invention.

DESCRIPTION OF THE EMBODIMENT

A liquid propellant gun, for example, as is shown in the FIGURE, comprises a gun barrel **10** having a bore **12**, a breech **14** having a bore **16** and a pair of swinging lock blocks **18** and **20**, an annular seal **22** at the interface of the barrel and the breech, and a gun bolt **24**. The gun bolt reciprocates in the bore **16** and enters and obturates the bore **12**. The bolt is locked in its obturating station by the lock blocks **18** and **20** which may be swung between the recesses **26** and **28** in the breech and the recesses **30** and **32** in the bolt. A projectile **34** may be chambered in the bore **12** and a supply of liquid propellant may be inletted into the chamber between the projectile and the bolt. An exemplary system is shown in Tassie, U.S. Pat. No. 3,763,739.

The gun bolt has a longitudinal bore therethrough having a first portion **38**, a shoulder **40**, a second portion **42** of smaller diameter than said first portion, a shoulder **44**, and a third portion **46** of smaller diameter than said second portion.

An igniter **50** is fixed within the bore of the gun bolt. The igniter comprises an outer tube **52**, an inner rod **54**, a volume **56** of irregular tightly packed together particles spacing the rod concentrically within the tube, except proximal to the face **58** of the bolt, wherein a void **60** to serve as a spark chamber is provided between the tube **52** and the rod **54**. An annulus **62** may be fixed within the void to close the exposed end face of the volume of particles. In an exemplary igniter, the tube **52** is made of a relatively workable, conductive material such as **321** stainless steel, the rod **54** is made of **303** stainless steel wire, (both chosen for corrosion resistance) and the insulating material **56** is magnesium oxide powder (MgO). The annulus **62** is a hard fired ceramic bead. The seals **63** around the annulus **62** are made of a resilient material which is not soluble in the particular propellant or fuel which is to be ignited, e.g., fluorocarbon elastomer.

The igniter **50** is advantageously manufactured by compression techniques. In using a rotary swaging technique, the rod **54** is initially positioned within the empty tube **52**. The insulating powder **56** is poured into the tube and is either tamped or vibrated to a light degree of compaction. Alternatively, the rod **54** may be threaded into a number of crushable MgO beads, and this assembly slid into the empty tube **52**. The ends of the filled tube **52** are then closed, as by plugs or welding, to prevent the powder and wire from being forced out of the tube during subsequent compaction. The closed assembly of tube, rod and powder is fed into a set of rotating dies between hammers in a cage. As the dies rotate, they open and close on the tube to reduce its external diameter. The first pass collapses and eliminates all internal voids. Successive passes further reduce the diameter and increase the length of the assembly by the formula $V_1=V_2$ where V_1=volume before the pass and V_2=volume after the pass, and $\pi R_1^2 L_1=\pi R_2^2 L_2$. In essence, the tube and its internal parts are concurrently squeezed out from between the die. As an alternative to rotary swaging, drawing, rolling, press swaging, or plain hammering on an anvil die could be used.

After compaction, the aft portion **70** of the tube **52** is machined to reduce its external diameter and to produce a step or shoulder **72** which is congruent with the shoulder **44**, and the plugged ends are removed. The forward or pressure or chamber portion **74** of the tube **52** tightly fits into the bore postion **42** while the aft portion **70** loosely fits into the bore portion **46** and is brazed therein. The shoulders **72** and **44** are in tight abutment. The chamber end of the tube is welded at **76** (e.g. fusion process) to the shoulder **40** of the gun bolt.

The essential characteristic of the insulating powder is that it must be so tightly compressed by the outer tube **54** that there is no space left for any particle of that powder or for any part of any other element of the assembly to shift into under any pressure applied during use of the igniter. MgO was selected because it has good physical and dielectric properties at high temperature, and because its irregular particles interlock together and into the adjacent metal surfaces under swaging better than any other material presently known. Other metal oxide mineral dielectric material may be used.

The void **60** is provided by air blasting out a quantity of particles from the chamber end of the igniter to expose a length of the exterior surface of the inner conductor and interior surface of the outer tube to act as electrodes.

This process of manufacture of collapsing the outer tube about the loose powder and the center conductor so tightly that everything is interlocked and cannot move irrespective of externally applied pressure, provides an assembly which behaves as if it were a solid rod of metal having the handling characteristics of the outer tube. Thus, pressure pulses beating on the forward face of the igniter cannot in any way disturb any of the parts of the igniter unless the outer tube expands, thereby loosening the powder. The gun bolt tightly fits around the igniter and supports it as a sheath both radially and longitudinally.

The annulus **62** does not fail under pressure pulses because it is firmly and evenly supported by the compacted powder **56** in the direction of the force, i.e. longitudinally, of the pulses. In all other directions the force of the pulses is simultaneously equal, and subjects the annulus only to a compressive stress which it can easily withstand.

The function of the annulus **62** and its seals is to prevent contaminants within the combustion chamber from entering the chamber face of the volume of powder.

It may be noted that the manufacturing process of this invention is quite different than conventionally used in making dielectric powder filled conduit. In the manufacture of conduit there is a step to soften the powder in the conduit so that it will flow with respect to the inner and outer conductors when the conduit is bent, and a step to anneal the outer conductor. In contradistinction, the igniter of this invention must be rigid and permit no relative movement of its internal elements. The pressure pulses apply extremely high pressure on the surface and interior interfaces of the volume of powder. No give or movement of the outer tube or internal elements is permitted. In the conventional conduit there is no pressure on the surface or interior interfaces of the powder in the tube.

It should be noted that the invention herein is not limited to a single inner conductor, a plurality of mutually spaced apart conductors may be supported by the particles of dielectric material and held by the outer tube.

What is claimed is:

1. A process for the manufacture of an igniter comprising:

providing an assembly of an outer tube of conductive metal, an inner rod of a conductive metal, and an intermediate volume of irregular particles of metal oxide mineral dielectric material spacing said rod within said tube;

compressing and reducing the diameter of the outer tube radially about said intermediate volume and the rod to remove all voids in said intermediate volume and to interlock and imbed said particles of said intermediate volume with each other and the adjacent metal surfaces of said rod and said tube; and

removing a portion of said volume after said compressing step to provide a spark chamber wherein a portion of said inner rod is exposed to a portion of said outer tube.

2. A process according to claim **1** wherein:

said compressing step reduces the diameter and increases the length of said assembly.

3. A process according to claim **1** further including:

removing a portion of said volume after said compressing step to provide a spark chamber wherein a portion of said inner rod is exposed to a portion of said outer tube.

4. A process according to claim **1** further including:

fixing an end portion of said assembly which includes said spark chamber within an additional tube to provide additional radial support to said outer tube.

5. A process for the manufacture of an igniter comprising:

providing an assembly of an outer tube of conductive metal, an inner rod of a conductive metal, and an intermediate volume of irregular particles of metal oxide mineral dielectric material spacing said rod within said tube;

compressing and reducing the diameter of the outer tube radially about said intermediate volume and the rod to remove all voids in said intermediate volume and to imbed the peripheral particles of said volume into the adjacent surfaces of said tube and rod; and

removing a portion of said volume after said compressing step to provide a void at a first end of said volume, said void being defined by an exposed portion of said inner rod mutually confronting an exposed portion of said outer tube, and the end face of said volume.

6. A process according to claim **5** further including:

fixing said igniter into an additional tube to provide additional radial support to said outer tube.

7. A process according to claim **6** further including:

providing mutual interlocking shoulders on the exterior of said outer tube and the interior of said additional tube to preclude relative movement in one longitudinal direction.

* * * * *

United States Patent [19]

Ashley

[11] **4,231,282**

[45] **Nov. 4, 1980**

[54] **IGNITION SYSTEM**

[75] Inventor: **Eugene Ashley,** Burlington, Vt.

[73] Assignee: **General Electric Company,** Burlington, Vt.

[21] Appl. No.: **25,176**

[22] *Filed:* **Mar. 29, 1979**

[51] **Int. Cl.**[3] **F41F 1/04**

[52] **U.S. Cl.** **89/7**

[58] **Field of Search** .... 89/7, 1 K, 1 R; 137/512.1

[56] **References Cited**

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4,033,224	7/1977	Holtrop	89/7
4,050,349	9/1977	Graham	89/7
4,051,762	10/1977	Ashley	89/7

Primary Examiner—David H. Brown

[57] **ABSTRACT**

A feature of this invention is the provision of a booster charge of liquid propellant from a main supply to adiabatically compress a quantity of gas and then progressively inject the booster charge into the heated gas.

7 Claims, 2 Drawing Figures

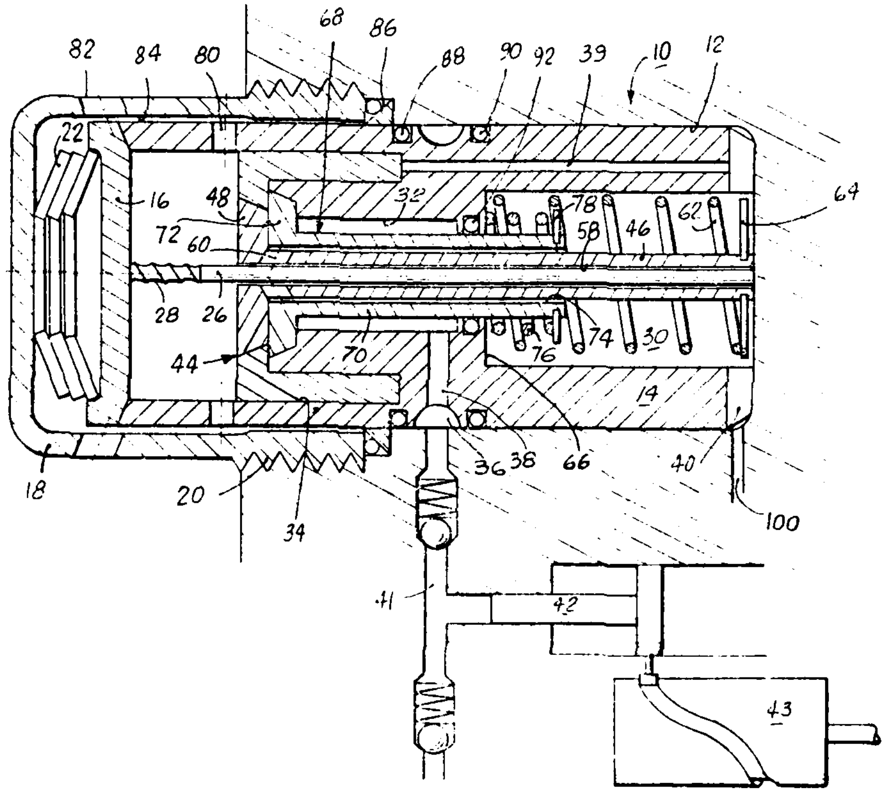

FIG. 1

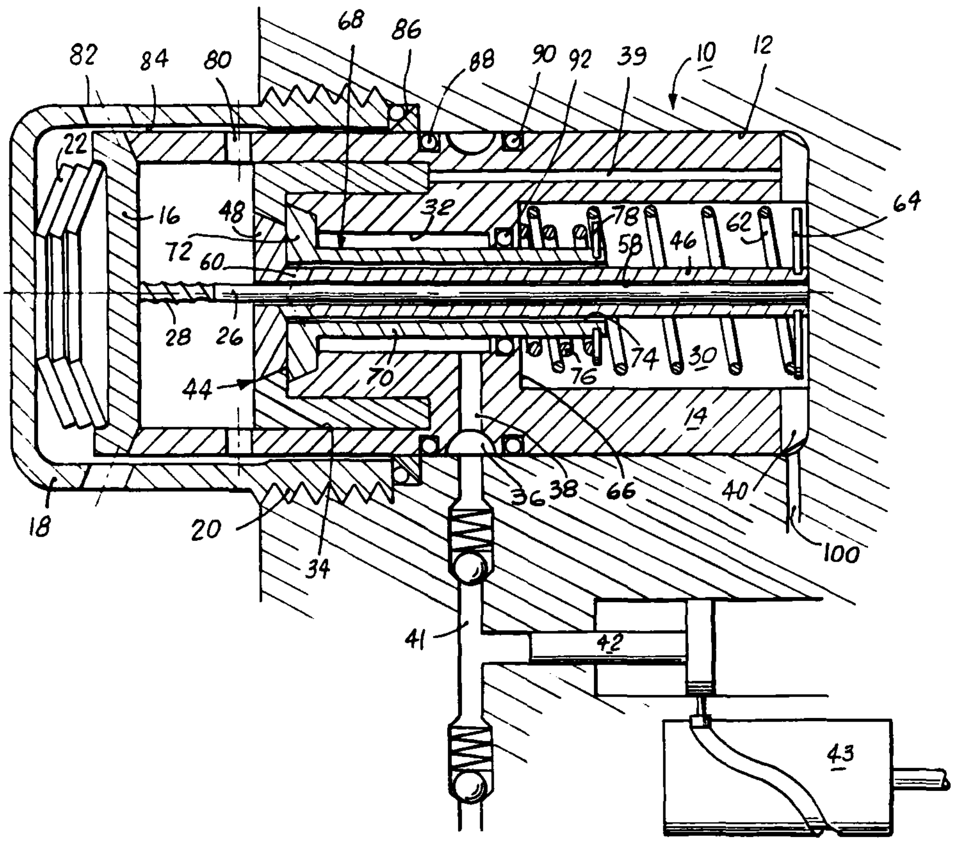
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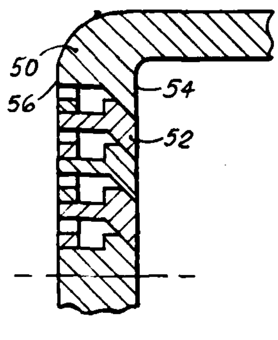
FIG. 2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IGNITION SYSTEM

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates to an ignition system, utilizing adiabatic heating of gas, for liquid propellants.

2. Prior Art

Liquid propellant guns are well known, and are shown, for example, in U.s. Pat. No. 4,023,463, issued to D. P. Tassie, on May 17, 1977 and in U.S. Pat. No. 4,051,762, issued to E. Ashley, on Oct. 4, 1977. Such guns, firing non-hypergolic propellants, require an initial pulse of hot, high pressure gas in the combustion chamber to start the firing process for each shot. For repetitive firing, sequential pulses must be provided. When pyrotechnic primers are utilized, the expended primer must be replaced after each shot as shown in U.S. Pat. No. 4,051,762. Electric spark ignition will work only with electrically conductive propellants, as shown in U.S. Pat. No. 4,023,463. Non-conductive propellants, such as Otto Fuel II, cannot be easily ignited. They must be confined and exposed to conditions of sufficient temperature and pressure for combustion to occur. U.S. Pat. No. 3,576,103, issued to P. B. Kahn, on Apr. 27, 1971, shows ignition of a monopropellant by adiabatic compression. This is accomplished by compressing a preloaded volume of propellant by means of a spring-loaded plunger which must be manually cocked and seared for each shot.

An object of this invention is to provide a series of adiabatic ignition pulses for non-hypergolic propellants for burst firing.

Another object is to provide each such pulse with an extended, controlled duration.

A feature of this invention is the provision of a booster charge of liquid propellant from a main supply to adiabatically compress a quantity of gas and then progressively inject the booster charge into the heated gas.

BRIEF DESCRIPTION OF THE DRAWING

These and other objects, features and advantages of the invention will be apparent from the following specification thereof taken in conjunction with the accompanying drawing in which:

FIG. 1 is a longitudinal cross-section of an ignition system embodying this invention; and

FIG. 2 is a detail of the structure of the differential piston of the ignition system of FIG. 1.

DESCRIPTION OF THE PREFERRED EMBODIMENT

An ignition system for liquid propellants which uses adiabatic compression of air or gas as the initiating source of combustion is shown in FIG. 1.

A housing **10** of a gun has a main combustion chamber with bore **12** in which is disposed in part a main body **14** of the igniter. A relief cap **16** is disposed on the projecting end of the body. A retaining cap **18** is threaded at **20** into the bore **12** and presses a plurality of belleville washers **22** against the relief cap **16** to seat the body **14** in the bore **12**. A valve rod **26** is fixed to the relief cap **16** and has a helical or other shaped relief groove **28** therein adjacent to said cap.

The valve body includes a longitudinally extending bore portion **30** of relatively large diameter, a longitudinally extending bore portion **32** of relatively small diameter, a longitudinally extending annular recess **34**, an annular groove **36**, a radially extending bore, or bores, **38** coupling said groove **36** and said bore portion **32**, and a longitudinally extending, fine bore, or bores, **39** coupling said recess **34** with a plurality of radial grooves **40**.

A supply line **41** for liquid propellant is coupled to the annular groove **36**. An injection piston **42** is coupled to the line **41** to meter a quantity of propellant through the bore **38** into the bore portion **32**. The piston may be driven by suitable periodic drive means, such as a cam **43** or a crank rod (not shown). A differential piston assembly **44** has a rod **46** and multipart head **48**. The head **48** is shown schematically in FIG. **1** and in greater detail in FIG. **2**, and is constructed in accordance with Ser. No. 2,038, filed Jan. 8, 1979 by E. Ashley. The head **48** has a relatively larger working area to its ignition chamber adjacent, or forward, face, and a relatively smaller working area to its supply chamber adjacent or aft face, and includes an outer annular sleeve **50** supporting one or more inner annuli **52**. The parts are interfitted and normally biased closed by the difference in pressure on the two faces of the piston head augmented by the force of the spring **62**, but permit limited relative movement to provide passageways through the head from the aft face **54** to the forward face **56** when the force on the aft face is greater than the force on the forward face, i.e., the equivalent of a plurality of poppet valves. The rod **46** and the head **48** have a longitudinal bore **58** therethroug in which is journaled the stationary valve rod **26**. A plurality of radially extending spray bores **60** extend through the piston rod **46** to the bore **58**. A helical spring **62** is captured between a clip **64** fixed to the aft end of the piston and a shoulder **66** on the bore portion **30**, and serves to bias the piston aft.

A unidirectional flow or check valve **68** has a valve rod **70** and a head **72** with a longitudinally extending central bore **74** in which is journaled the piston rod **46**. The check valve is of the type shown in U.S. Pat. No. 4,023,463, issued May 17, 1977, to D. P. Tassie. A helical spring **76** is captured between a clip **78** fixed to the aft end of the valve rod and the shoulder **66**.

A plurality of radial holes **80** are provided through the tubular wall of the body immediately forward of the piston head, when the piston head is in its aftmost position.

A plurality of radial holes **82** are provided through the tubular wall of the retaining fitting **18** aligned with the interface of the relief cap **16** and the body.

An annular gap **84** is provided between the outer cylindrical surface of the body and the inner cylindrical surface of the retaining fitting in the region between the holes **80** and **82**.

Ring seals are provided at **86**, **88**, **90** and **92**.

Liquid propellant is forced through the bore **38** into the bore portion **32** by the injection piston **42** at high pressure. The liquid shifts the check valve and the differential piston forwardly, so that liquid passes through the developed gap between the head of the check valve and the body against the aft face of the head of the differential piston. The pressure on the aft face of the head is greater than the pressure on the forward face, maintaining the rings of the piston head closed together.

As the differential piston moves forwardly it closes off the holes **80**, trapping gas between the front face of the differential piston and the relief cap **16**, which with the adjacent inner wall of the body, define an ignition chamber. Before the first shot, the gas will be air, but

after firing the gas will be a mixture of air and combustion products. Continuing forward movement of the differential piston, against the bias of its spring, under the influence of the entering high pressure liquid from the injection piston, continues to compress the gas. This movement is rapid so that a minimum of heat is lost to the walls, and a maximum of heat is retained by the compressed gas. This forward movement and gas compression continue until the holes **60** come over the helical relief groove **28** on the stationary valve rod. Liquid pressure is higher than gas pressure, by Pascal's Law, and liquid propellant is forced through the holes **60** and the relief groove into the combustion chamber. The groove is designed to discharge the liquid propellant as a spray into the combustion chamber where it contacts the hot compressed gas therein and ignites.

As soon as this liquid propellant begins to burn in the confined combustion chamber, the pressure of the gas in the combustion chamber will rise. When the force developed by the gas pressure forward of the piston head exceeds the force developed by liquid pressure aft of the piston head, regenerative action begins. The rings of the piston head open and the piston head and the check valve head move aft, initially closing the check valve. The charge of liquid propellant trapped forward of the check valve is progressively injected through the open rings of the differential piston head into the combustion chamber as the differential piston head is forced aft by the combustion gas pressure. The holes **80** through which the air originally entered will not be exposed and opened until the differential piston has almost completed its aftward stroke. The high temperature combustion gas is passed out of the combustion chamber, to ignite the main charge of liquid propellant in the gun, when the combustion gas pressure becomes sufficiently high to compress the bellevile washers **24** to unseat the relief cap **16** to allow the combustion gas to flow out through the holes **82**. This occurs before the completion of the differential piston stroke, and as the differential piston continues its aftward movement, a sustained pulse of ignition gas is passed out through the holes **82**.

The fine bore 39 and the groove **40** provide a vent to allow leakage to be relieved to a passageway **100** in the housing **10** of the gun, which opens to atmospheric pressure. This vent also serves to provide the differences in area between the front and the rear faces of the differential piston head.

The advantages of this igniter may be recapitulated as:

1. No pyrotechnic primer or electrical firing pulse is required to initiate ignition.

2. The ignition charge of liquid propellant can be repetitively and accurately metered into the igniter.

3. The regenerative piston provides a prolonged flow or pulse of ignition gas for ignition of the main liquid propellant charge.

4. Any convenient mechanical or hydraulic means can be used to repetitively provide the initiating liquid injection pressure.

I claim:

1. An ignition system for liquid propellant comprising:
- a first chamber;
- a piston having a head disposed in said first chamber and dividing said first chamber into an ignition chamber and a liquid propellant supply chamber;
- means for admitting gas into said ignition chamber;
- unidirectional flow valve means for admitting liquid into said supply chamber and for blocking loss of liquid therefrom;
- means for providing under pressure a predetermined quantity of liquid propellant through said unidirectional flow valve means into said supply chamber, whereby said liquid propellant causes translation of said head of said piston in a first direction to enlarge the volume of said supply chamber and to decrease the volume of said ignition chamber, to compress and thereby heat the gas;
- first means effective upon the translation of said head to a predetermined minimal volume of said ignition chamber for passing an initial quantity of liquid propellant from said supply chamber into said ignition chamber for ignition by the therein compressed and heated gas, whereby the ignited liquid propellant provides an increase in gas pressure in said ignition chamber and causes translation of said head of said piston in a second direction opposite to said first direction to enlarge the volume of said ignition chamber and to decrease the volume of said supply chamber; and
- second means effective upon the translation of said head in said second direction to progressively pass the remaining quantity of liquid propellant from said supply chamber to said ignition chamber during the course of movement in said second direction of said head.

2. An ignition system according to claim **1** wherein: said gas admitting means includes
- additional means for providing a passageway into said ignition chamber;
- said additional means being open when said head of said piston defines the minimum volume of said supply chamber; and
- said additional means being closed when said head of said piston defines significantly more than the minimum volume of said supply chamber.

3. An ignition system according to claim **1** further including:
- means for regularly, periodically operating said liquid propellant providing means.

4. An ignition system according to claim **1** wherein: said head of said piston has a face adjacent said ignition chamber of a relatively larger working area and a face adjacent said supply chamber of a relatively smaller working area.

5. An ignition system according to claim **4** wherein: said second means includes
- means for providing a passageway through said head of said piston from said supply chamber adjacent face to said ignition chamber adjacent face;
- said passageway means being closed when the pressure applied to said supply chamber adjacent face is higher than the pressure applied to said ignition chamber adjacent face; and
- said passageway means being open when the pressure applied to said supply chamber adjacent face is lower than the pressure applied to said ignition chamber adjacent face.

6. An ignition system according to claim **1** further including:
- means for venting ignited liquid propellant from said ignition chamber.

7. An ignition system according to claim **6** wherein: said venting means includes

yet additional means for providing a passageway from said ignition chamber;

said yet additional means being closed when the pressure in said ignition chamber is below a predetermined value; and

said yet additional means being open when the pressure in said ignition chamber is above a predetermined value.

* * * * *

PATENTS ASSIGNED TO PULSEPOWER SYSTEMS, INC.

Patent Number: 3,800,657
Author: Thomas M. Broxholm, Palo Alto, CA; Lester C. Elmore, Portola Valley, CA
Title: Modular Liquid Propellant Gun
Date: April 2, 1974

Patent Number: 3,803,975
Author: Lester C. Elmore, Portola Valley, CA; Thomas M. Broxholm, Palo Alto, CA
Title: Liquid Propellant Weapon
Date: April 16, 1974

Patent Number: 3,916,792
Author: Lester C. Elmore, Portola Valley, CA; Thomas M. Bruxholm, Palo Alto, CA
Title: Liquid Propellant Weapon
Date: November 4, 1975

Patent Number: 4,161,904
Author: William Groen, San Jose, CA; Lester C. Elmore, Portola Valley, CA
Title: Liquid Propellant Modular Gun Incorporating Hydraulic Pressurization of the Case
Date: July 24, 1979

Patent Number: 4,164,889
Author: Lester C. Elmore, Portola Valley, CA; Thomas M. Broxholm, Palo Alto, CA
Title: Liquid Propellant Modular Gun Incorporating Dual Cam Operation and Internal Water Cooling
Date: August 21, 1979

Patent Number: 4,164,890
Author: Lester C. Elmore, Portola Valley, CA; Thomas M. Broxholm, Palo Alto, CA
Title: Liquid Propellant Modular Gun Incorporating Dual Cam Operation and Internal Water Cooling
Date: August 21, 1979

United States Patent [19]

Broxholm et al.

[11] 3,800,657

[45] Apr. 2, 1974

[54] MODULAR LIQUID PROPELLANT GUN

[75] Inventors: Thomas M. Broxholm, Palo Alto; Lester C. Elmore, Portola Valley, both of Calif.

[73] Assignee: Pulsepower Systems Incorporated, San Carlos, Calif.

[22] Filed: Jan. 7, 1971

[21] Appl. No.: 104,610

[52] U.S. Cl. .... 89/7, 89/1 L

[51] Int. Cl. F41f 1/04

[58] Field of Search .... 89/7, 8, 9, 1 L, 11, 12, 89/1, 161

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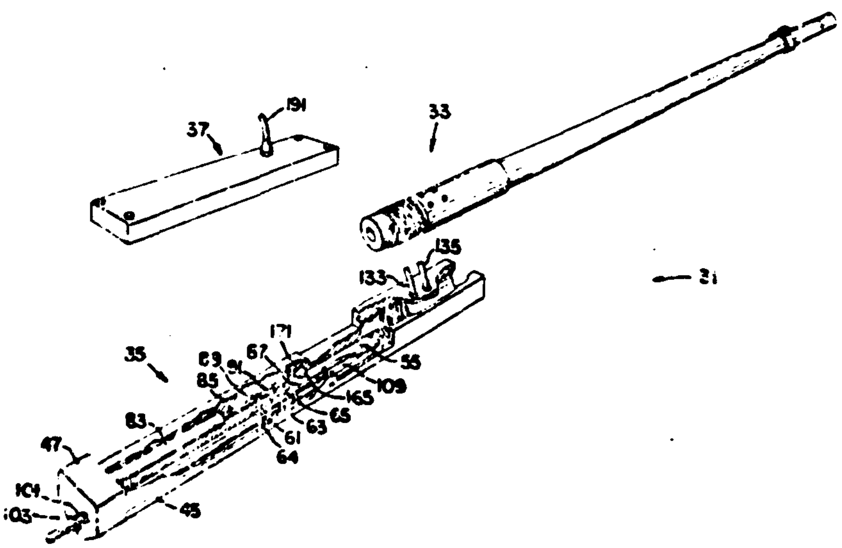
Primary Examiner—Samuel W. Engle
Attorney, Agent, or Firm—Owen, Wickersham & Erickson

[57] ABSTRACT

A gun of the kind in which liquid propellant is burned in the firing chamber to fire a projectile from the gun is constructed so that a number of gun modules can be combined in a modular gun. Each gun module is cam controlled, and a common cam is used to control each gun module in the modular gun. The cam can be a flexible cam having a belt configuration to permit the gun modules to be arranged in both circular groupings and in non-circular groupings, such as side by side. The modular gun includes fixed, non-rotating gun modules to eliminate the need for tangential velocity correction factors in the fire control and the need to accelerate the mass of the barrel assembly to operational speed. The individual gun module includes propellant injection mechanism for injecting propellant at high pressure when a non-hypergolic bi-propellant is used as the propellant. One or more hydraulic actuators are used to develop the high injection pressures and to operate other components of the gun, such as the bolt. The hydraulic actuators are also engaged with the cam to interlock the actuators and the controls for the actuators through the cam. A source of pressurized hydraulic fluid independent of the gun is used to power the actuators so that the weight and profile of the gun are kept to a minimum. The hydraulic system includes a compound spool control valve which operates in a dual mode to permit normal cyclic operation of the gun during firing and to maintain the gun in an open bolt condition during armed but non-firing operations. The hydraulic system includes a misfire detection mechanism and module shutdown valve which locks a misfired gun module in the closed bolt condition with the need to depressurize the hydraulic circuits of the other gun modules and without the need to include additional bypass circuits. The injection mechanism for injecting the bi-propellant includes two pistons which are yoked together and operated by a single actuator to inject the propellant into the firing chamber both in metered amounts and in a constant mix ratio. The pistons for injecting the bi-propellant include valves in the pistons, and the pistons are drawn through the fuel on retraction strokes of the pistons. The injection mechanism is retracted away from the firing chamber after the firing of a burst to isolate the propellant in the injection mechanism from the heat of the firing chamber. A rotary lock is mounted closely adjacent the bolt mechanism and engages a relieved area of the bolt in the locked position of the lock so that a quite small force on the lock will hold the bolt mechanism locked against high combustion chamber pressures tending to open the bolt.

14 Claims, 33 Drawing Figures



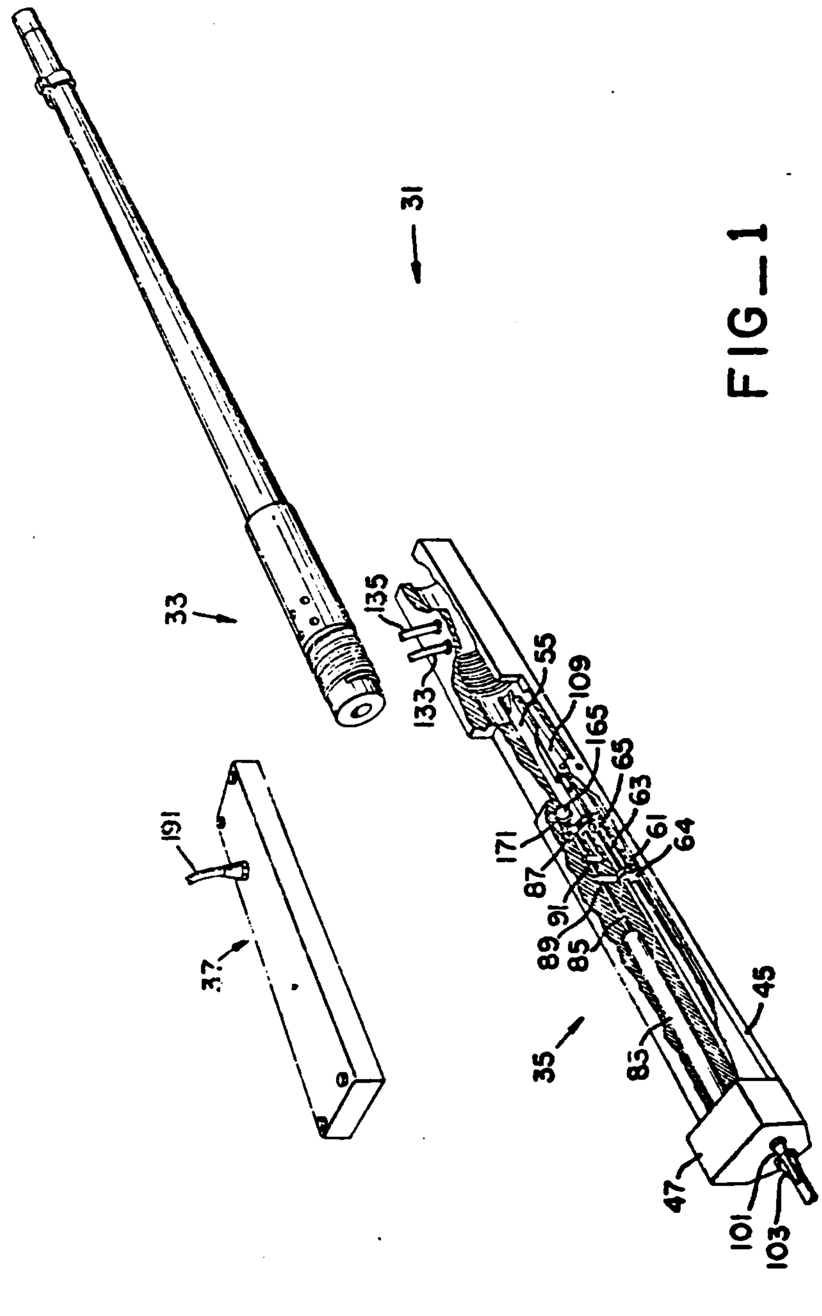


FIG_1

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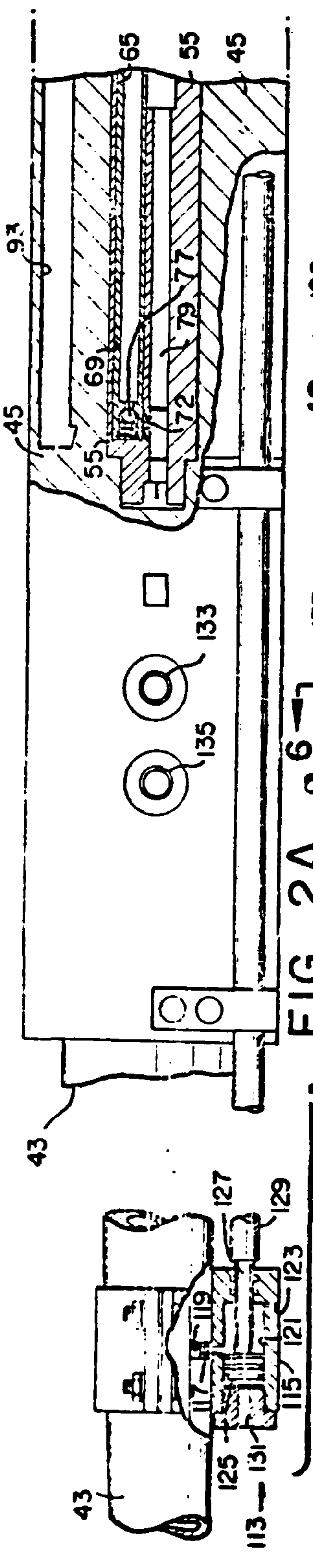

FIG_2A

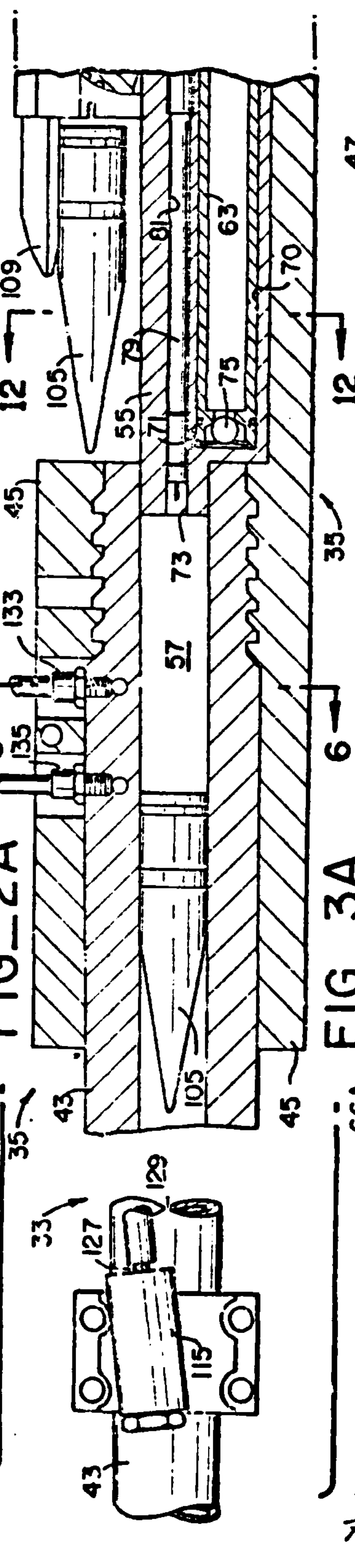

FIG_3A

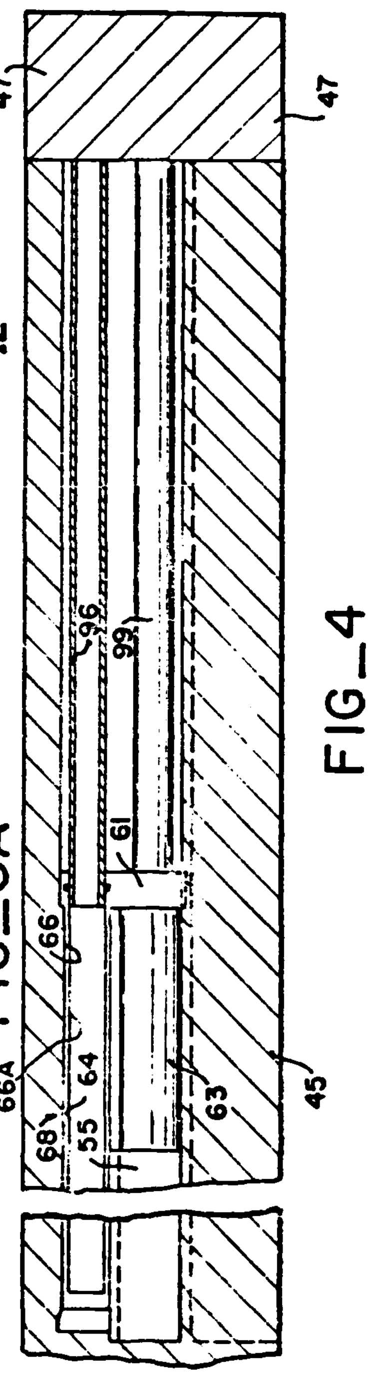

FIG_4

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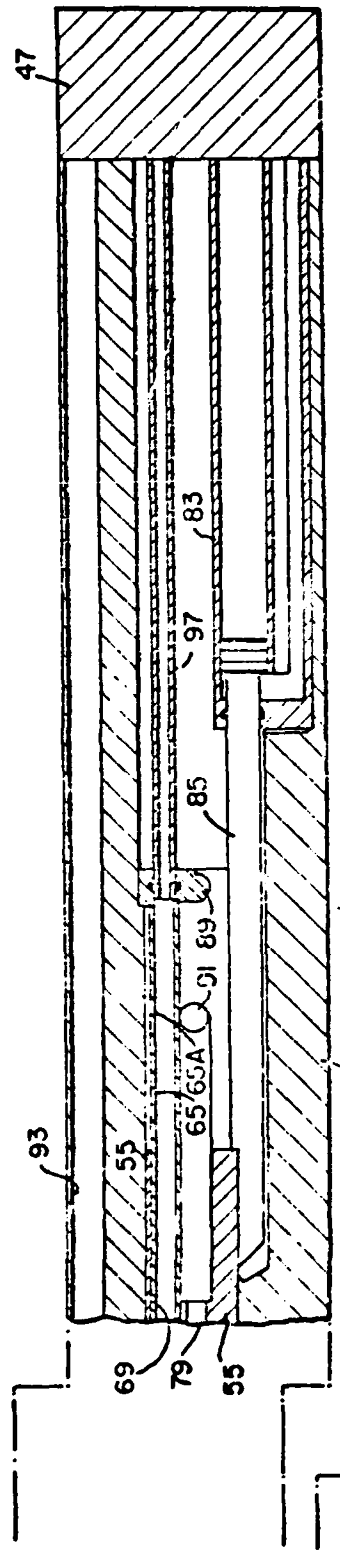

FIG_2B

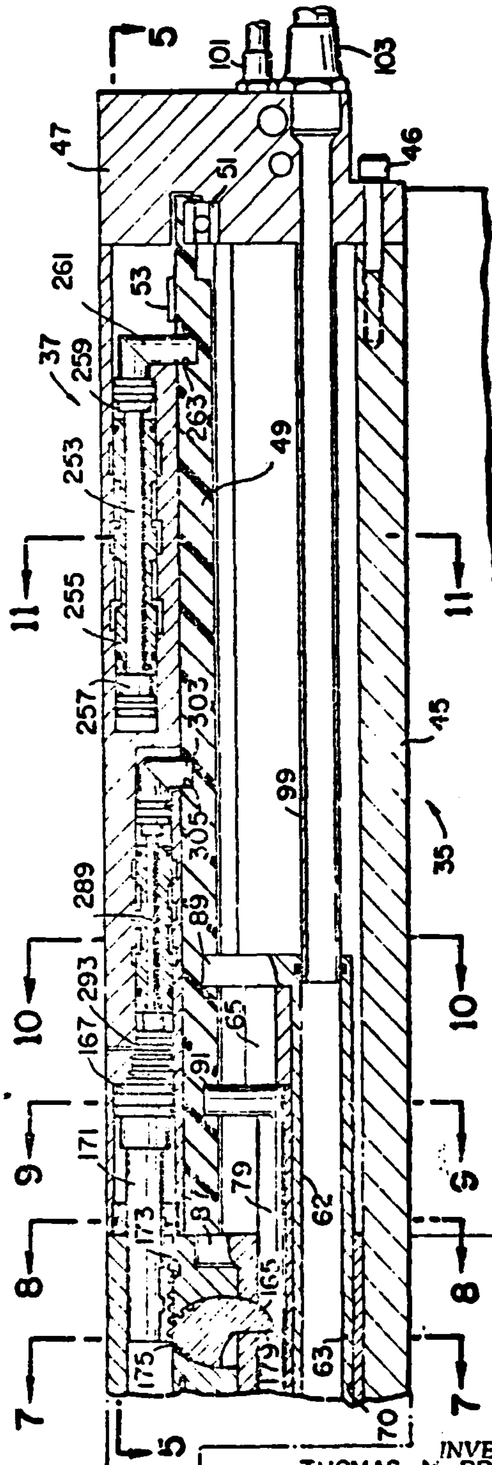

FIG_3B

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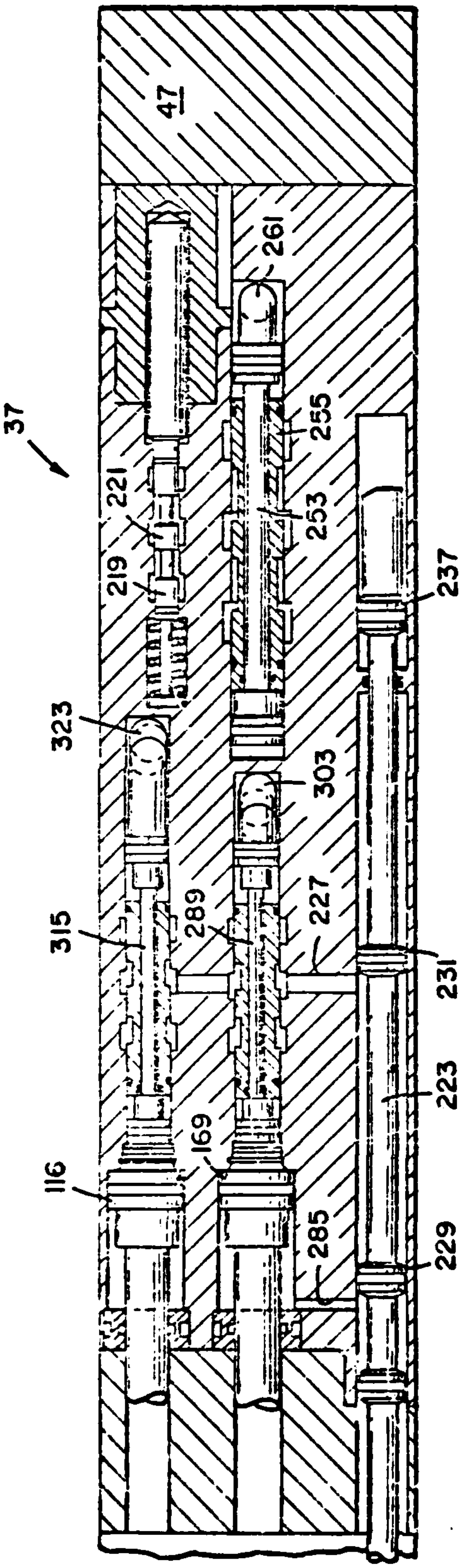

FIG_5

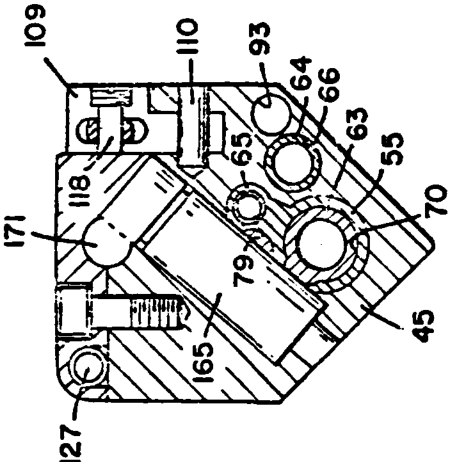

FIG_7

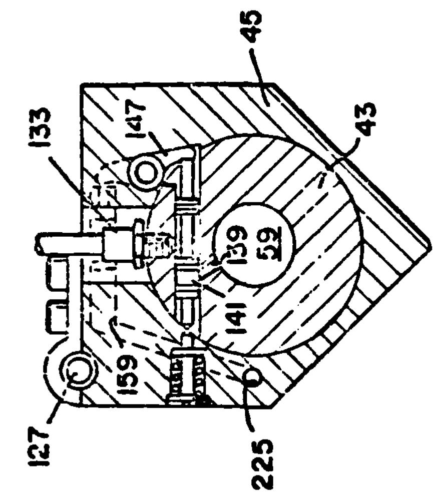

FIG_6

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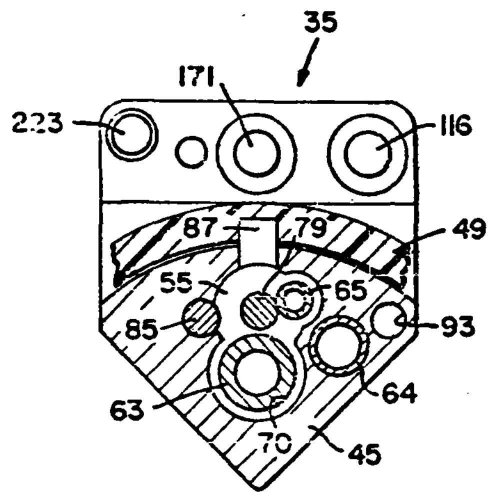

FIG_8

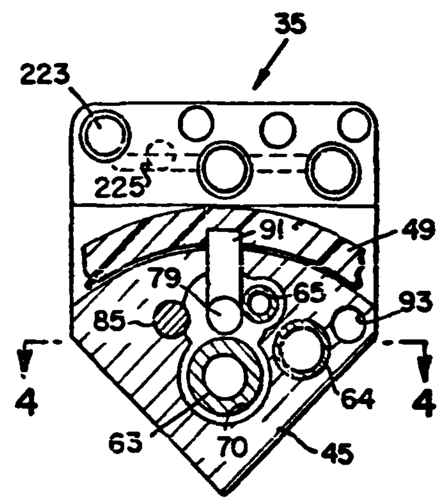

FIG_9

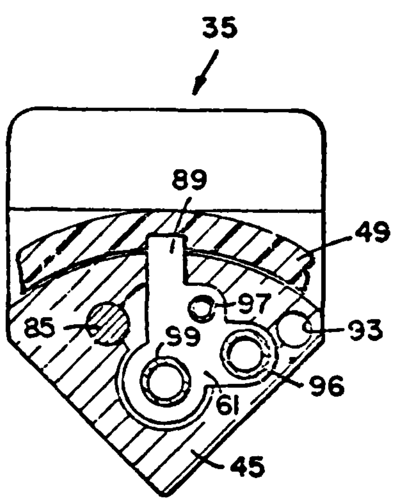

FIG_10

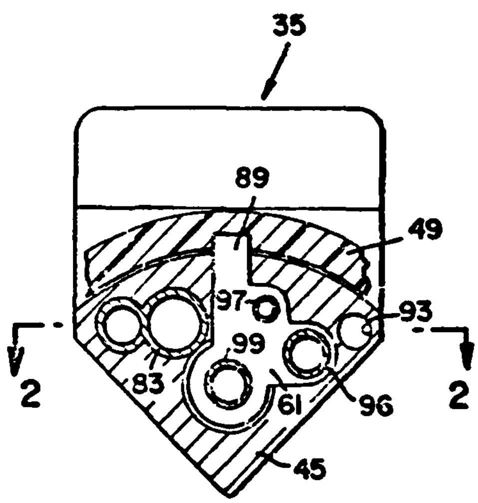

FIG_11

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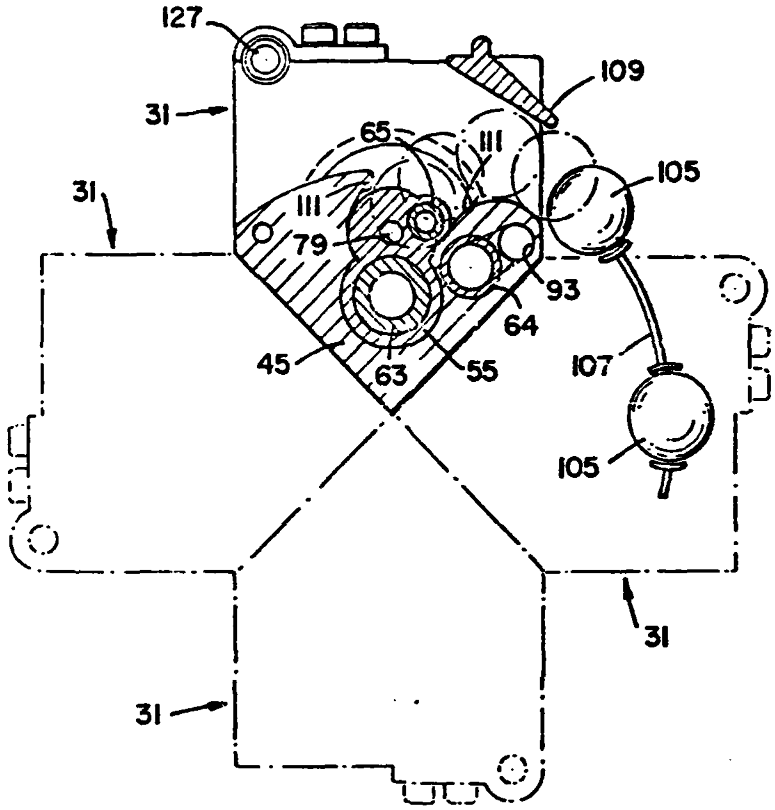

FIG_12

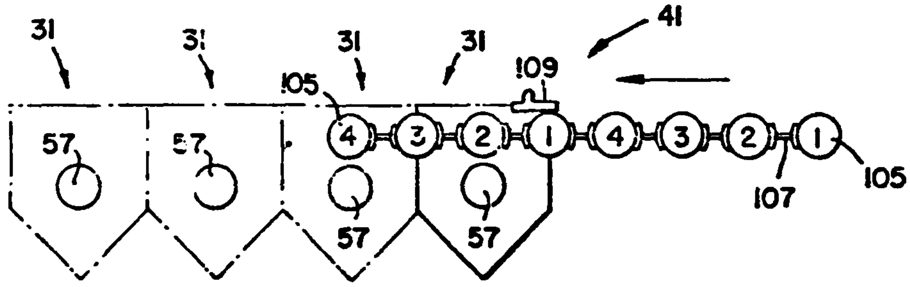

FIG_13

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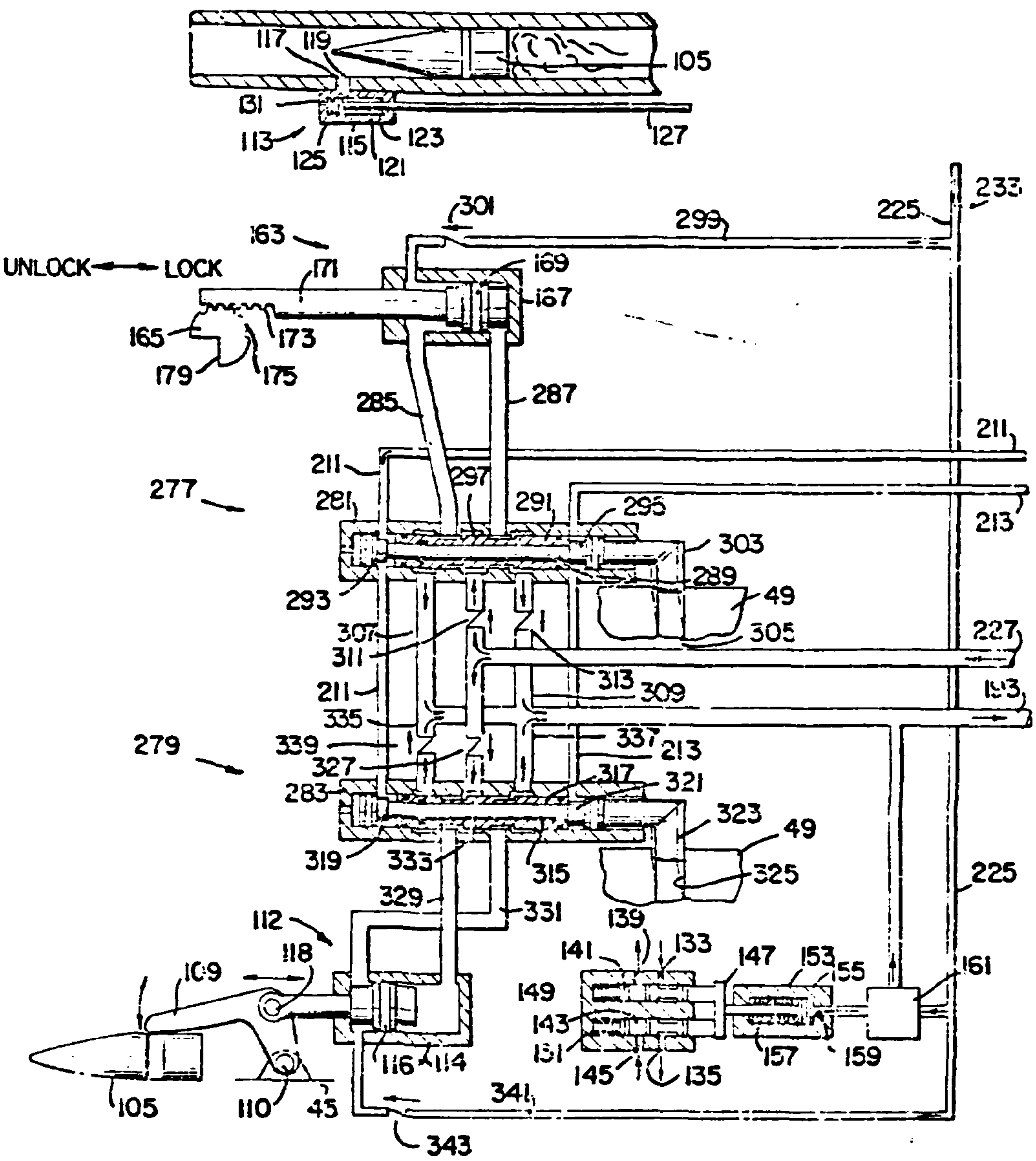

FIG_14A

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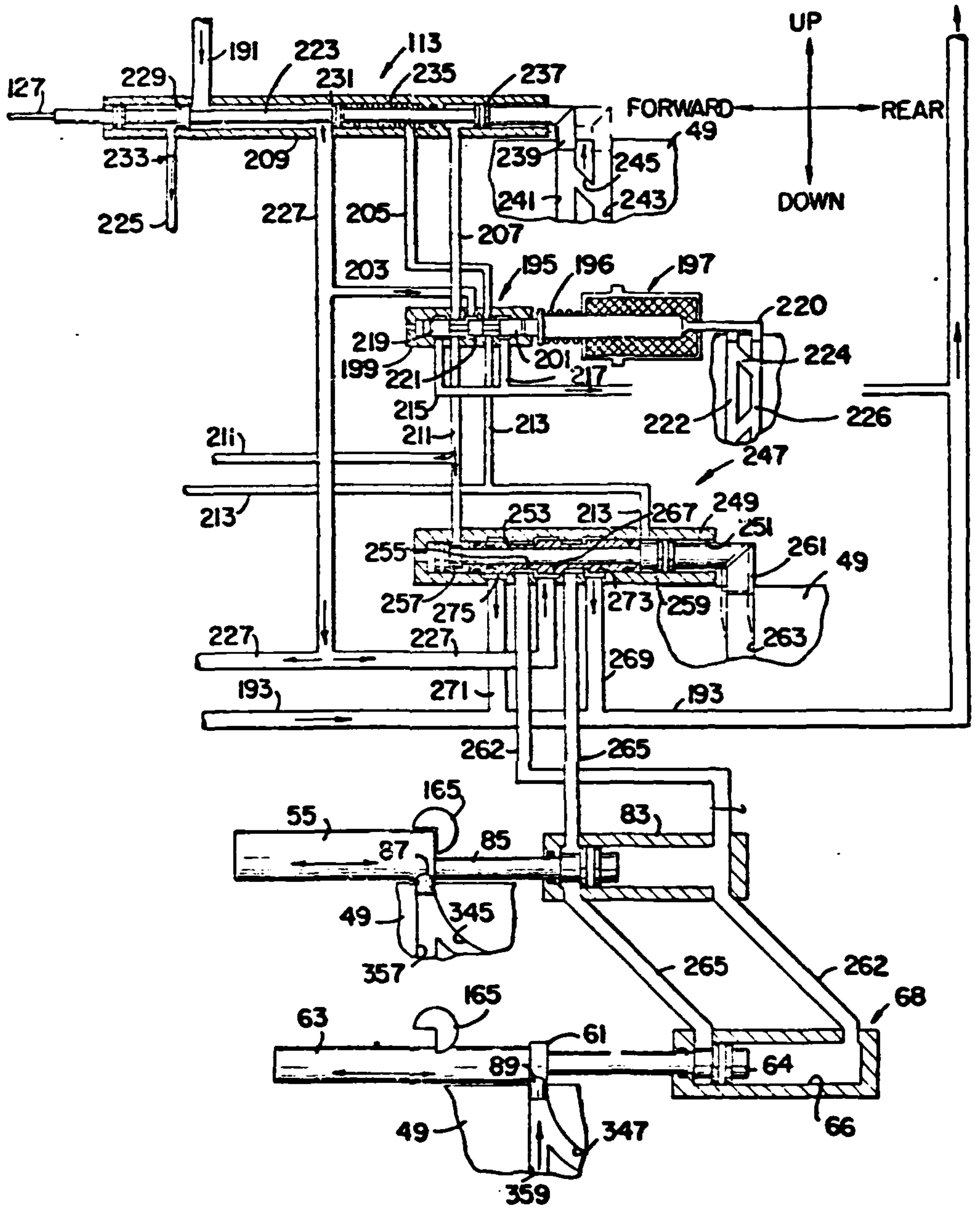

FIG_14B

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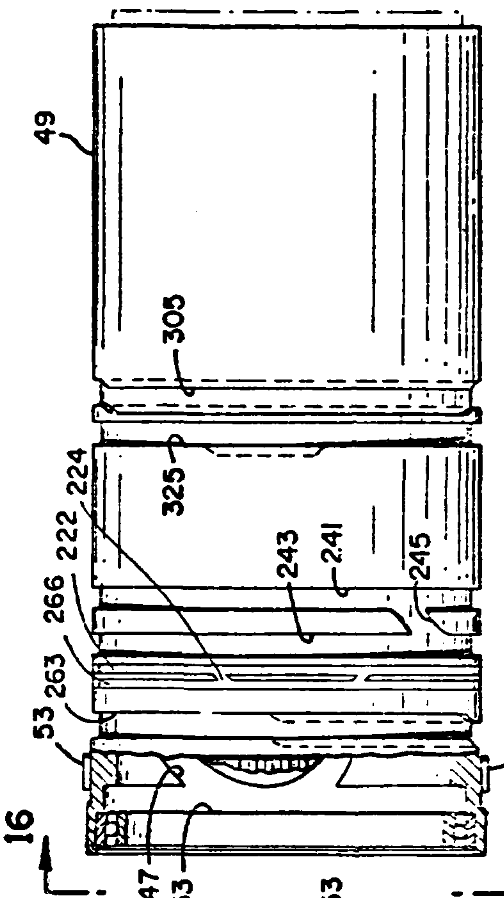

FIG_15

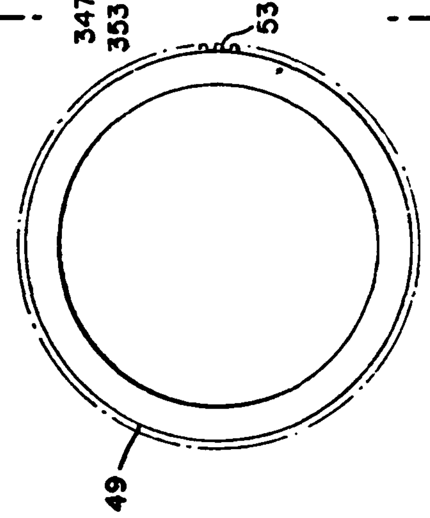

FIG_16

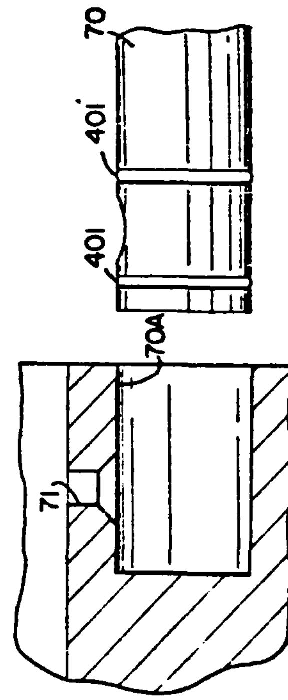

FIG_17A

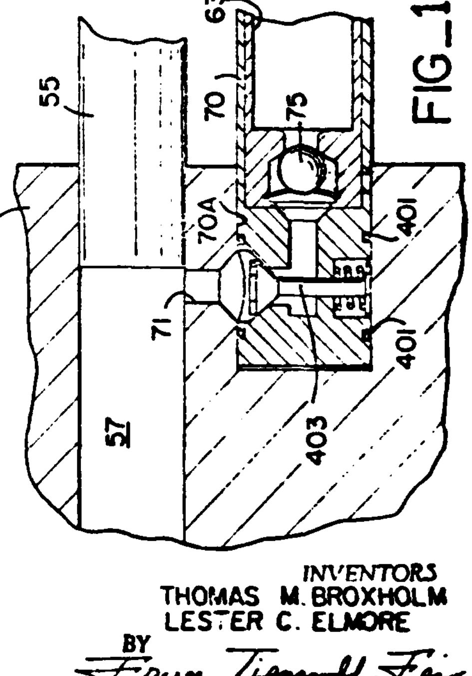

FIG_17

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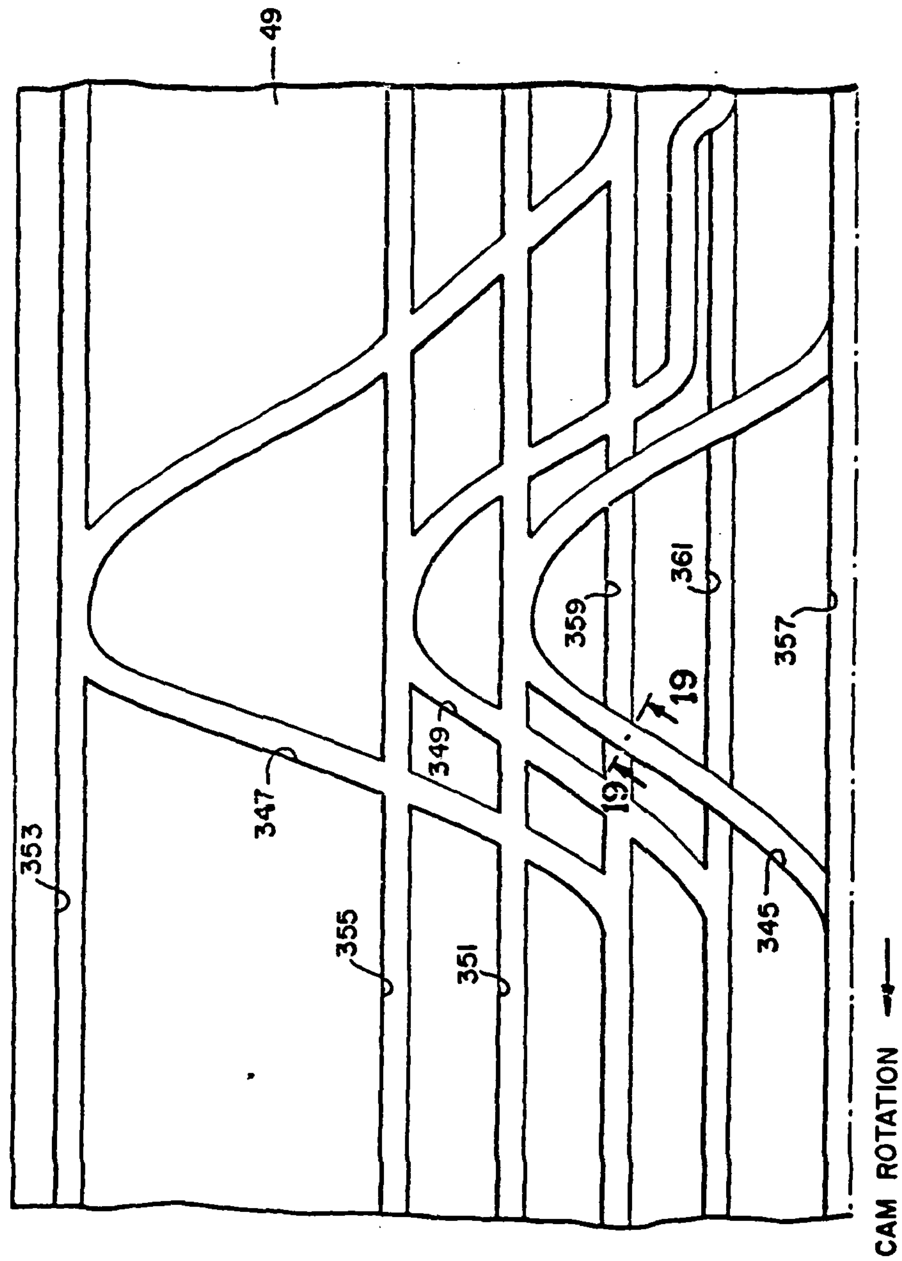

FIG_18

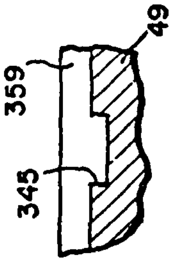

FIG_19

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FIG_20

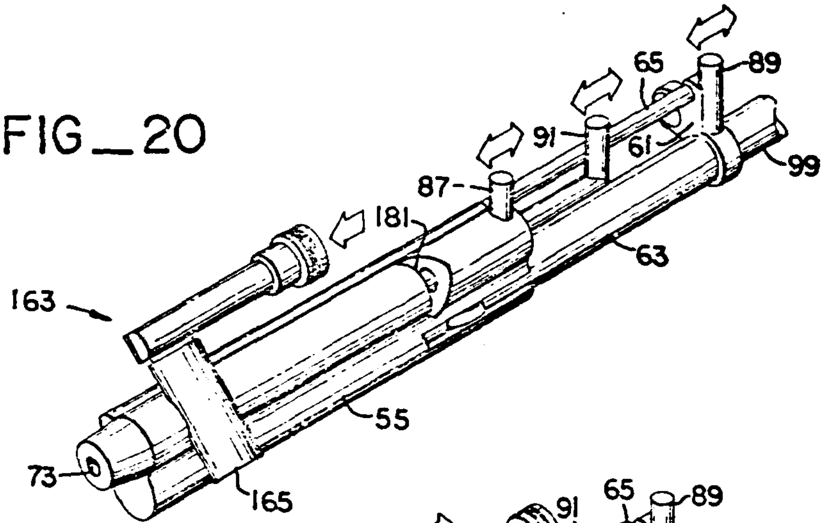


FIG_21

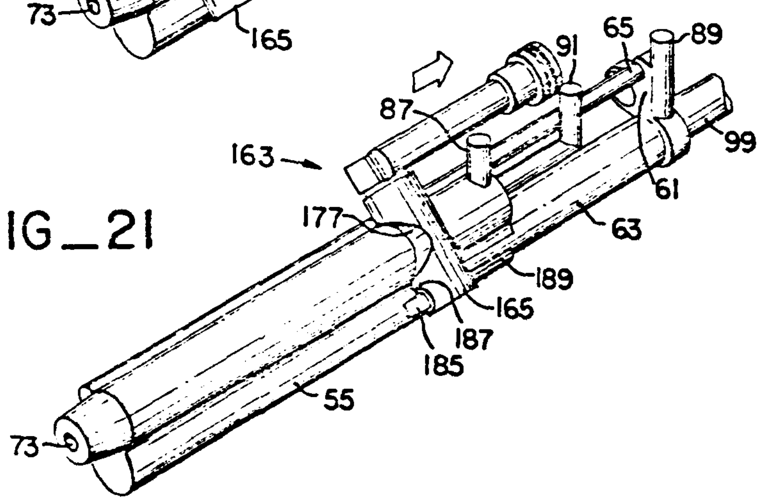
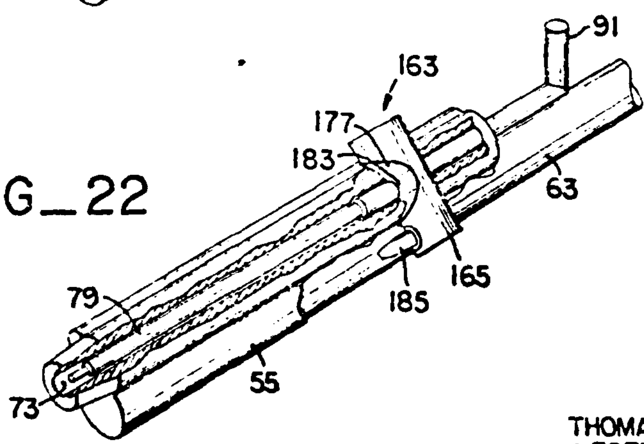


FIG_22



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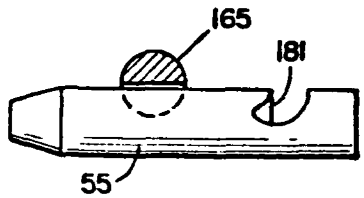

FIG_23

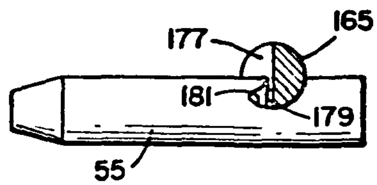

FIG_24

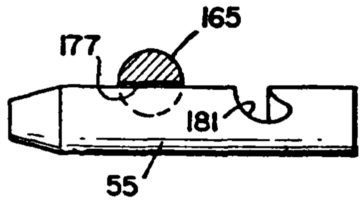

FIG_25

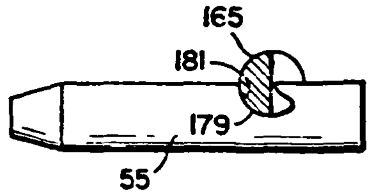

FIG_26

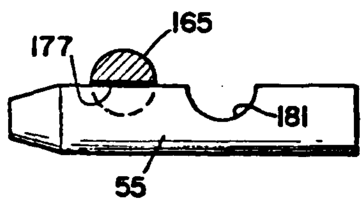

FIG_27

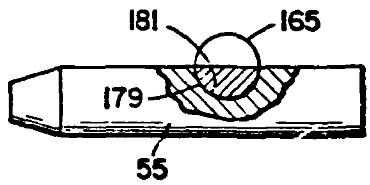

FIG_28

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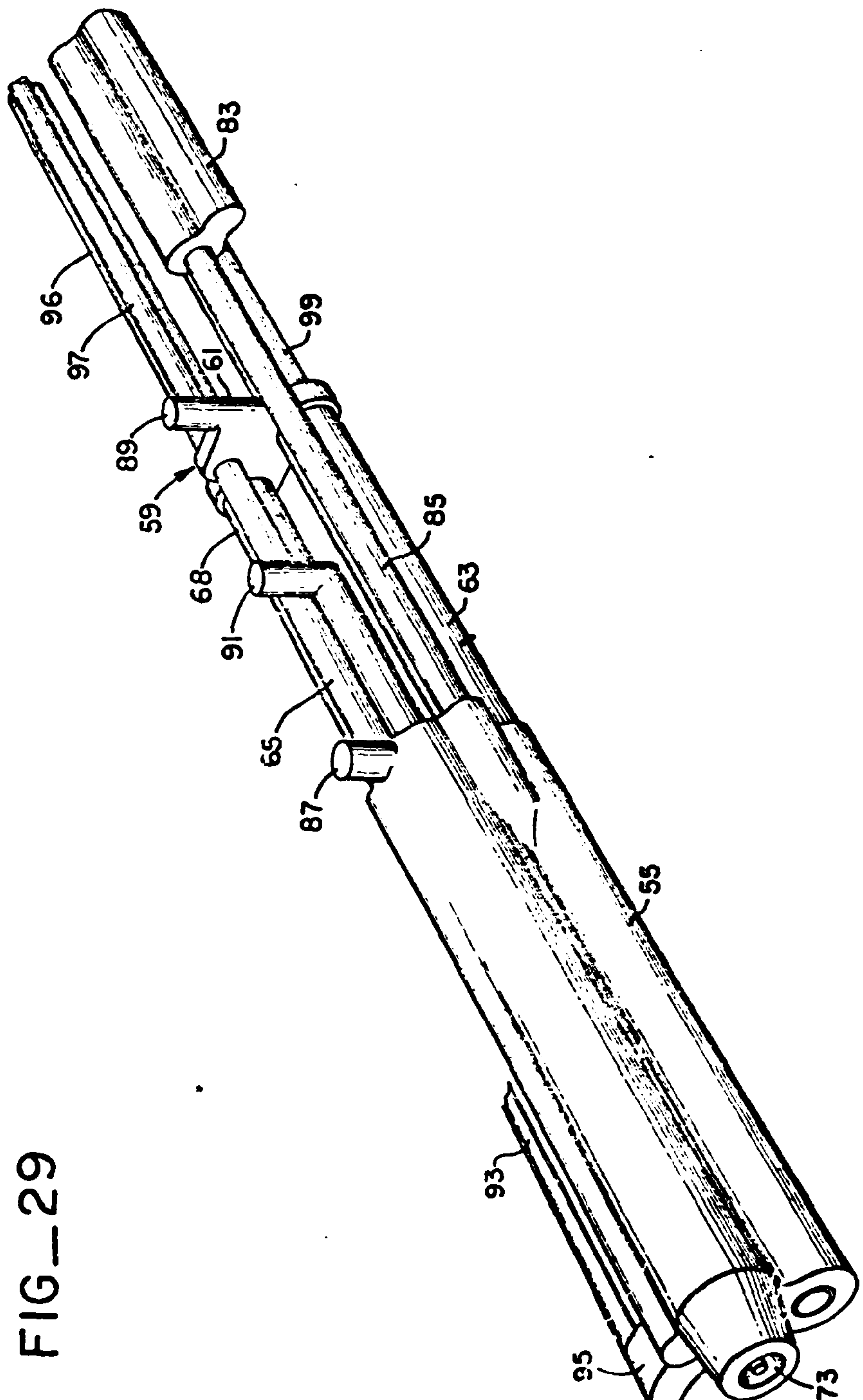

FIG_29

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UNITED STATES PATENT OFFICE

CERTIFICATE OF CORRECTION

Patent No. 3,800,657 Dated April 2, 1974

Inventor(s) Thomas M. Broxholm and Lester C. Elmore

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

Column 6, line 25, "belt 105" should read --belt 107--. Column 8, line 16, "lock 265" should read --lock 165--. Column 12, line 32, "controls the fluid" should read --controls the flow of fluid--; line 50, "viave" should read --valve--. Column 13, line 27, "Fliuid" should read --Fluid--. Column 14, line 1, "beore" should read --before--. Column 15, line 15, "rewarward" should read --rearward--. Column 16, line 36, delete "during"; line 52, delete "tf of rear"; line 52, add --or rear-- in first column after "Cam Follower Position"; line 52, add --forward-- in third column after "Cam Follower Position"; line 53, "rer" should read --rear--. Column 17, line 13, "with However, piston." should read --with the piston.-- Column 18, line 31, "rotaes" should read --rotates--; lines 56 and 57, "hydraluic" should read --hydraulic--.

In the Claims:

Column 21, line 17 of Claim 12, "for" should read --mounting--. Column 21, line 17 should read --chamber, mounting means mounting the injection mechanism--. Column 22, line 6 of Claim 13, "injection" should read --injecting--.

Signed and sealed this 1st day of October 1974.

(SEAL)
Attest:

McCOY M. GIBSON JR.
Attesting Officer

C. MARSHALL DANN
Commissioner of Patents

MODULAR LIQUID PROPELLANT GUN

This invention relates to a gun of the kind in which liquid propellant is burned in the firing chamber to fire the projectile from the gun.

This invention relates particularly to a liquid propellant gun constructed as an individual gun module so that a number of gun modules can be combined in a modular gun.

In conventional guns powder for firing each projectile is carried in a case attached to the projectile.

A liquid propellant gun has a number of advantages over such conventional guns.

If a liquid propellant gun uses the same size projectile as a conventional gun, the projectile feed for the liquid propellant gun can be simplified and can be made considerably lighter in weight than for a conventional gun. Or, a considerably larger charge can be used for higher performance without having to increase the size of the projectile feed mechanism.

A liquid propellant gun can produce a flatter combustion chamber pressure-time characteristic than a solid propellant gun. Hence performance equivalent to a solid propellant gun can be obtained at lower pressure.

High cyclic rates of fire are possible with a liquid propellant gun.

Because the propellant is a liquid the propellant can be easily pumped to the firing chamber from a storage area remote from the gun itself. This permits flexibility of installation.

When the gun is installed in an aircraft and a non-hypergolic bi-propellant is used, one of the components of the non-hypergolic bi-propellant can be the fuel used for the engine of the aircraft.

The liquid propellant gun permits a low profile, clean exterior design so that an individual liquid propellant gun module, or a modular grouping of liquid propellant gun modules, can be installed in locations that would not accommodate a conventional gun.

It is a primary object of the present invention to incorporate these inherent advantages of a liquid propellant gun in a modular gun.

Further objects of the present invention include the specific structures and features of operation noted in the abstract above.

Other and further objects of the present invention will be apparent from the following description and claims and are illustrated in the accompanying drawings which, by way of illustration, show preferred embodiments of the present invention and the principles thereof and what are now considered to be the best modes contemplated for applying these principles. Other embodiments of the invention embodying the same or equivalent principles may be used and structural changes may be made as desired by those skilled in the art without departing from the present invention and the purview of the appended claims.

IN THE DRAWINGS

FIG. 1 is an isometric exploded view (partially broken away to show details of construction) of an individual gun module constructed in accordance with one embodiment of the present invention. FIG. 1 shows the three main components of an individual gun module—the barrel assembly, the receiver assembly, and the control assembly;

FIG. 2A and FIG. 2B are a plan view (partly broken away along the line and in the direction indicated by the arrows 2—2 in FIG. 11) of the gun shown in FIG. 1;

FIG. 3A and FIG. 3B are a side elevation view in cross section of the gun module shown in FIG. 1;

FIG. 4 is a fragmentary plan view taken generally along the line in the direction indicated by the arrows 4—4 in FIG. 9;

FIG. 5 is a fragmentary top plan view taken generally along the line and in the direction indicated by the arrows 5—5 in FIG. 3B;

FIG. 6 is an elevation view taken along the line and in the direction indicated by the arrows 6—6 in FIG. 3A;

FIG. 7 is an elevation view taken along the line and in the direction indicated by the arrows 7—7 in FIG. 3B;

FIG. 8 is an elevation view taken along the line and in the direction indicated by the arrows 8—8 in FIG. 3B;

FIG. 9 is an elevation view taken along the line and in the direction indicated by the arrows 9—9 in FIG. 3B;

FIG. 10 is an elevation view taken along the line and in the direction indicated by the arrows 10—10 in FIG. 3B;

FIG. 11 is an elevation view taken along the line and in the direction indicated by the arrows 11—11 in FIG. 3B;

FIG. 12 is an elevation view taken along the line and in the direction indicated by the arrows 12—12 in FIG. 3A. FIG. 12 illustrates how four individual gun modules can be arranged in a circular grouping in a modular gun constructed in accordance with an embodiment of the present invention;

FIG. 13 is a schematic front end elevation view illustrating the way in which the projectiles are spaced at one half the pitch between adjacent gun modules. FIG. 13 illustrates how four individual gun modules may be arranged side by side in a modular gun constructed in accordance with an embodiment of the present invention;

FIG. 14A and FIG. 14B are a schematic diagram of a hydraulic drive control system for a single gun module as shown in FIG. 1;

FIG. 15 is a top plan view of a cam having a hollow cylindrical configuration for use with four gun modules arranged in a circular grouping as best illustrated in FIG. 12. Parts of FIG. 15 have been broken away to show the cam faces on the interior surface of the hollow cylindrical cam;

FIG. 16 is an end view of the cam shown in FIG. 15 and is taken along the line and in the direction indicated by the arrows 16—16 in FIG. 15;

FIG. 17 is a fragmentary cross sectional view like FIG. 3A showing a modification of the fuel injection mechanism for the gun module shown in FIG. 1. FIG. 17A illustrates how the propellant injection mechanism is retracted away from the firing chamber after the firing of a burst;

FIG. 18 is an inside developed view of the inside surface of the hollow cylindrical cam shown in FIG. 15;

FIG. 19 is a fragmentary cross section view taken along the line and in the direction indicated by the arrows 19—19 in FIG. 18;

FIG. 20 is a pictorial view of one embodiment of a bolt locking mechanism for the gun module shown in FIG. 1. FIG. 20 shows the bolt locking mechanism in the unlocked mode;

FIG. 21 is a view like FIG. 20 showing the lock mechanism in the locked mode;

FIG. 22 is a view like FIG. 21 but with parts partially broken away to show details of construction;

FIGS. 23 and 24 are side elevation views of the lock mechanism of FIGS. 20–21 showing the bolt and lock in the unlocked position in FIG. 23 and in the locked position in FIG. 24;

FIGS. 25 and 26 are views like FIGS. 23 and 24 of another embodiment of a lock mechanism constructed in accordance with the present invention;

FIGS. 27 and 28 are views like FIGS. 23 and 24 of still another embodiment of the lock mechanism constructed in accordance with the present invention; and

FIG. 29 is a pictorial view of the bolt and actuator sub-assembly.

An individual gun module constructed in accordance with one embodiment of the present invention is indicated generally by the reference numeral 31 in FIG. 1.

The gun module 31 includes three main components—a barrel assembly 33, a receiver assembly 35, and a control assembly 37.

The gun module 31 may be used by itself or (as will be described in greater detail below) may be arranged in both circular groupings (as shown in FIG. 12) or in non-circular groupings (as shown in FIG. 13) to form modular guns. The modular guns are indicated generally by reference numerals 39 and 41 in FIGS. 12 and 13.

The gun module 31 is a liquid propellant gun. The gun burns a liquid propellant in the firing chamber to propel the projectile.

The particular embodiment of the gun 31 shown in the drawings and described below is constructed to use a bi-propellant, a propellant having two components which are mixed in the firing chamber. The gun module 31 shown in FIG. 1 uses a non-hypergolic bi-propellant. The two components of the bi-propellant do not ignite on contact.

Non-hypergolic bi-propellants have this advantage over hypergolic bi-propellants. The non-hypergolic bi-propellant can be handled in the same way as a mono-propellant. For example, the firing chamber can be fired, without spontaneous ignition, as in a mono-propellant. Because of this fact, the chamber can be fired without having to pump against combustion pressure; and the propellant can be loaded in an exact amount before ignition is started. It should be noted, however, that many of the principles of the present invention could be applied to liquid propellant guns using hypergolic bi-propellants. Most of the principles of the present invention can be applied to liquid propellant guns using mono-propellants.

The bi-propellant is ignited in the combustion chamber by a spark plug in the embodiment of the gun module shown in FIG. 1. Ignition can also be accomplished by compression ignition or by injecting a chemical into the propellant. The present invention is not restricted to spark ignition.

The gun module 31 is a cam-controlled, hydraulically powered gun. The main cam maintains a proper sequence and timing relationship between the various components of the gun while hydraulic power is the primary energy source.

The cam for controlling the gun module 31 is shown in FIGS. 15, 16, 18 and 19.

A hydraulic drive control system of the control assembly 37 is shown in schematic diagram in FIGS. 14A and 14B.

The bolt and injector sub-assembly of the receiver assembly 35 is shown in FIG. 29.

Details of construction of the gun module 31 will now be described with reference primarily to FIGS. 3A and 3B and FIGS. 2A and 2B.

The barrel assembly 33 includes a barrel 43.

The receiver assembly 35 includes a receiver 45.

The receiver assembly 35 also includes an end plate 47 attached to the back end of the receiver 45 by a number of cap screws 46.

The hydraulic control assembly 37 is mounted on the receiver 45 in front of the end plate 47.

A main cam 49 is mounted for rotation between the receiver 45 and the hydraulic control assembly 37. The main cam 49 is a hollow, cylindrical member (as best shown in FIGS. 15 and 16), and the rear end of the cam 49 is mounted for rotation on a bearing 51 in the end plate 47. The front end of the cam 49 may also be mounted for rotation on a bearing (not shown in the drawings) or may rotate on the receiver 45. The cam 49 has cam traces on both the inside and the outside peripheries. As will be described in greater detail below, the cam traces on the inside peripheries engage cam followers of actuators in the receiver 45 while the cam traces on the outside periphery engage cam followers of control valves in the hydraulic control assembly 37.

The cam 49 in the embodiment shown in FIG. 12 can be a rigid member. In other applications, e.g., the FIG. 13 embodiment, the cam 49 must be a flexible member as illustrated to accommodate non-circular groupings of modules. As will become more apparent from the description to follow, a flexible cam is possible because of the low cam face loads of the present invention. The low cam face loads are possible because the cam does not drive the bolt assembly. The force for driving the bolt assembly is supplied by hydraulic actuators, and the cam serves only to maintain the proper phase relationship between the actuators and the control valves.

The cam 49 includes gear teeth 53 on the outside periphery of the cam. An electric or hydraulic motor (not shown in the drawings) drives the cam (in counterclockwise rotation as viewed in FIGS. 8–11) by means of the gear teeth 53.

The receiver 45 mounts a bolt 55 and propellant injection mechanism for reciprocation toward and away from combustion chamber 57 at the inlet end of the barrel 43.

The bolt and injector sub-assembly is best illustrated in FIG. 29. In FIG. 29 the propellant injection mechanism 59 includes a yoke 61, an acid piston 63, a fuel piston 65 and a hydraulic actuator 68. In the embodiment of the invention shown in FIGS. 2A, 2B, 3A, 3B and FIG. 29, the acid piston reciprocates within a cylinder 70 formed in the bolt 55, and the fuel piston 65 reciprocates within a cylinder 69 formed in the bolt 55.

The acid, or oxidizer, component of the bi-propellant is injected from the cylinder 70 through a port 71 into a central bore or pre-combustion chamber 73 of the bolt 55 and then into the combustion chamber 57.

The fuel in an aircraft installation may be the same fuel (such as JP 4) used for the aircraft engine. The fuel is injected from the cylinder 69 into the pre-combustion chamber 73 and the combustion chamber 57 through a port 72 shown in FIGS. 2A.

Piston 63 includes a one-way check valve 75 at the forward end of the piston.

The piston 65 includes a one-way check valve 77 at the forward end of the piston.

These check valves permit the fuel to flow through the interior of the pistons and through the head of the piston into the cylinder 70 and the cylinder 69 during the retraction strokes of the pistons within the cylinders 70 and 69.

The strokes of the pistons 63 and 65 are the same since the pistons are yoked together by the yoke 61. The proper mix ratio for the two components of the bi-propellant is obtained by the relative diameters of the pistons 67 and 65. The two components of the bi-propellant are therefore injected into the firing chamber in both metered amounts and in a constant mix ratio.

A spark plug 79 is mounted for reciprocation within the bolt 55 in a bore 81 which forms a continuation of a pre-combustion chamber 73.

The spark plug 79 closes off the propellant injection port 71 of the cylinder 70 and the port 72 for the cylinder 69 as the spark plug is moved forward during a cycle of operation to control the end of the propellant injection strokes.

As best shown in FIG. 29, the bolt is actuated by a hydraulic actuator 83 and an actuator rod 85.

The bolt 44 includes a bolt cam follower 87.

The fuel injection yoke 61 includes a cam follower 89.

The spark plug includes a spark plug cam follower 91.

With continued reference to FIG. 29, the hydraulic fluid for the propellant injection mechanism actuator 68 is brought in through a hydraulic line 93 and a hydraulic port 95.

The fuel for the fuel piston 65 is supplied through a fuel line 97.

The oxidizer for the acid piston 63 is supplied through a line 99.

The injector actuator 68 includes a piston 64 slidable in a bore 66. The piston 64 in turn has an inner bore 66A.

The injector actuator hydraulic line 96 (see FIG. 4 and FIG. 29 and also FIG. 10) slides within the bore 66A in a trombone type arrangement as the injector yoke 61 is reciprocated back and forth by the action of the piston 64 within the bore 66.

As best shown in FIGS. 2B and 3B, the fuel piston and fuel line and the acid piston and acid line also have similar trombone type arrangements.

Thus, the fuel piston 65 has a hollow interior forming a bore 65A, and this hollow bore slides back and forth on the outside of the fuel line 97 during reciprocation of the piston 65 by the yoke 61.

The acid piston 63 has a bore 62, and this bore 62 slides back and forth on the exterior of the acid line 99 as the acid piston 63 is reciprocated by the yoke 61.

Suitable seal means, as shown in the drawings, are provided to accomplish the necessary sealing.

As best shown in FIG. 3B, the fuel line 97 is connected through the end plate 47 to a fuel port 101, and the acid line 99 is connected through the end plate 47 to an acid port 103.

FIG. 3A shows the bolt 55 at its full forward position.

A projectile 105, as shown in FIG. 3A, has been forced forward to the position illustrated by the forward movement of the bolt 55 and also by the liquid propellant injected behind the projectile 105 into the firing chamber 57 by the forward movement of the fuel piston 65 and the acid piston 63. The projectile 105 is forced forward by the liquid propellant injected in the chamber 57. The forward motion is stopped by the resistance produced by the forcing cone. The way in which the projectile is loaded into the receiver and forced forward by the bolt and the liquid propellant insures that the firing chamber 57 and pre-combustion chamber 73 are completely filled with liquid propellant to eliminate an ullage problem.

The projectile 105 may preferably be fed to the receiver by a linkless belt 105 as shown in FIG. 12.

As shown in FIG. 12 (and as also shown in the lower lefthand corner of FIG. 14A), a projectile loader lever 109 bats a projectile 105 out of the belt 107 and into a curved slot 111 shaped to drop the projectile 105 into the proper position in the receiver assembly 31 in front of the bolt 55.

The projectile loader lever 109 is in the form of a bell crank (as best shown in FIG. 14A) and is pivotally connected to the receiver 45 by a pin 110.

The lever 109 is pivoted about the pin 110 by a hydraulic actuator indicated generally by the reference numeral 112 in FIG. 14A.

The actuator 112 includes a housing 114 and a piston 116 reciprocable within a bore in the housing. A rod of the piston 116 is connected to the lever 109 in a pin-joint connection 118.

As shown in FIG. 3A the projectile 105 in the receiver above the bolt 55 is positioned to be moved downward and in front of the front face of the bolt 55 by the lever 109 when the bolt 55 is retracted.

Each gun module 31 includes a misfire detection and module shutdown system. This system will be described in detail with reference to FIGS. 14A and 14B, but at the present time it should be noted that the system includes a detector mechanism indicated generally by the reference numeral 113 in FIG. 2A. The mechanism 113 includes a housing 115 clamped to the front end of the barrel 43 by bolts and nuts as illustrated. The housing 115 has a restricted orifice 117 which fits within an opening 119 in the barrel. The orifice 117 opens into a cylinder 121 in the interior of the housing 115. A second restricted orifice 123 also communicates with the interior of the cylinder 121 and extends through the wall of the housing 115 to connect the cylinder with the ambient atmosphere.

A piston 125 is reciprocable within the cylinder 121.

A piston rod 127 extends from the rearward end of the piston 125 through an end wall of the housing 115 and through a tube 129 back to a module shutdown control valve 223 as shown in FIG. 14B and as will be described in greater detail below.

An opening 131 extends through the front end wall of the housing 115 to vent the cylinder in front of the piston 125 to ambient atmosphere to prevent lock-up.

The orifices 117 and 123 are controlled orifices. The high pressure gas behind the projectile 105 enters the chamber within the cylinder 121 behind the piston 125 through the orifice 117 as the projectile is fired out of the barrel 43. The orifices 117 and 123 permit the escape of the pressurized gas from the interior of the housing 115 at a controlled rate to provide a certain leak down time. If another projectile is not fired within this leak down time the piston rod 127 is pulled back (to the right as viewed in FIG. 2A) by hydraulic pressure exerted on a face of the control valve, as will be described in greater detail below with reference to FIG. 14B.

The detection mechanism 113 thus detects a misfire. The detection mechanism 113 remains in the position illustrated in FIG. 2A so long as the gun module continues in normal cyclic operation and does not misfire. On a misfire the piston 125 is shifted rearward (to the right as viewed in FIG. 2A).

As shown in FIGS. 2A and 3A an inlet port 133 and an outlet port 135 are connected to the top of the barrel 43 through openings in the receiver 45 for supplying fluid to the combustion chamber 57 to purge the chamber 57 in the event of a misfire.

As best shown in FIG. 6 the fluid from the inlet port 133 flows into the combustion chamber 57 through a port 139 when a valve member 141 is positioned to permit flow between the ports 133 and 139.

As best shown in FIG. 14A a companion valve 143 controls the flow of the purge fluid out of the combustion chamber 57 through a port 145 (like the port 139) and through the outlets of 135 to sump.

As shown in FIG. 14A the valve members 141 and 143 are yoked together by a yoke 147 and spring biased, by springs 149 and 151, to the positions illustrated in which the valve members close off the ports 139 and 145.

A hydraulic actuator 153, which includes a piston 155 spring biased by the spring 157 to the position illustrated in FIG. 14A, opens the ports 139 and 145 by moving the valve members 141 and 143 to the left as viewed in FIG. 14A when hydraulic pressure is admitted to the interior of the actuator 153 through the conduit 159. The flow of hydraulic fluid through the conduit 159 is under the control of a three-way time control valve 161. The three-way time delay valve 161 is controlled by the misfire detection and module shutdown system, as will be described in greater detail with reference to the description of FIGS. 14A and 14B.

As best shown in FIGS. 20–22 the gun module 31 includes a breech lock mechanism. This breech lock mechanism is indicated generally by the reference numeral 163 in FIGS. 20–22.

The breech lock mechanism, as best shown in FIG. 14A, includes a lock 165 and an actuator 167.

The actuator 167 includes a piston 169 and a rod 171. The forward end of the rod 171 has gear teeth 173 which engage corresponding gear teeth 175 on the lock. The rod 171, gear teeth 173 and gear teeth 175 form a rack-and-pinion arrangement for rotating the lock 165.

The lock 165 is a cylindrical member mounted for rotation about its longitudinal axis. The rotational axis of the lock 165 extends transverse to the axis of reciprocation of the bolt 55.

The lock 165 has a cutout or relieved area 177 which permits the lock to be mounted with the rotational axis of the lock closely adjacent to the outer periphery of the bolt 55. The relieved area 177 is shaped to, in effect, let the bolt reciprocate within the lock 165 with the outer periphery of the bolt in closely adjacent relationship to the surface of the cutout 177 of the lock when the lock is in the unlocked position.

The bolt 55 has a similar cutout or relieved area 181 which provides an abuttment face when the lock 165 is rotated into the cutout or relieved area 181.

This action is best shown in FIGS. 23 and 24.

In the configuration of the parts shown in FIGS. 23 and 24 the lock 265 has an abuttment face 179. The face 179 abutts the corresponding abuttment face 181 of the bolt 55, which is a part of the relieved area 177 of the lock 165.

FIGS. 25 and 26 and FIGS. 27 and 28 show modified lock and bolt arrangements in which the abuttment face 179 of the lock is not part of the relieved area 177 of the lock.

In this instance, however, the abuttment face 179 of the lock engages a substantial part of the relieved area of the bolt in the locked position so that only a small force exerted by the actuator 167 is required to hold the bolt in the locked position.

Since the combustion pressure developed in the combustion chamber 57 is quite large, the force on the forward face of the bolt 55 during firing is also quite large. This force on the face of the bolt acts in a direction tending to open the bolt, and it is therefore important that the lock mechanism 163 be effective to hold the bolt in the locked position.

As best illustrated in FIG. 22 the spark plug 79 also has a cutout or relieved area which engages the lock 165 when the lock 165 is rotated to the locked position.

As also illustrated in FIGS. 21 and 22, the piston 63 of the propellant injection mechanism may also be formed with a locking element 185 projecting outwardly from the piston 63 for engagement with a locking face 187 of the lock 165 when the lock is rotated to the locked position.

The locking element 185 is slidable within a slot 189 of the bolt 65. The locking of the fuel injection mechanism is not as critical as the locking of the bolt 55 and the spark plug 79 because the fuel injection mechanism is not directly exposed to the combustion pressure within the combustion chamber 57.

Before going to a discussion of the control mechanism shown in FIGS. 14A and 14B, it should be noted that FIG. 17 and 17A illustrate a modification of a propellant injection mechanism. In these figures the cylinder 70 and piston 63 are mounted for reciprocation within a bore 70A formed in the barrel 43 and in the receiver 45 rather than in the bolt 55.

The cylinder 70 has a front end portion constructed to withstand the high pressures developed during combustion in the combustion chamber 57.

Seals, such as O-rings 401, prevent the loss of combustion chamber pressure.

A spring biased check valve 403 is mounted in the front end portion of the cylinder 70 to permit the flow of propellant from the cylinder through the port 71 to the combustion chamber.

The piston 63 includes a one-way check valve 75 at the forward end of the piston.

In the operation of the embodiment shown in FIGS. 17 and 17A, the cylinder 70 remains in the forward position illustrated in FIG. 17 during the firing of a burst while the piston 63 reciprocates back and forth within the cylinder 70 during the firing of each round. After the firing of a burst, the entire cylinder 70 and piston 63 assembly is retracted to the position shown in FIG. 17A to isolate the propellant from the hot barrel 43.

The present invention retracts the propellant injection mechanism away from combustion chamber 57 so that the injection mechanism and the liquid propellant within the injection mechanism are physically isolated from the hot combustion chamber to provide a thermal barrier, that is, a physical barrier to prevent heat flow from the hot combustion chamber to the propellant. This eliminates problems of heat soak which can lead to cookoff or unwanted vaporization of fuel and combustion in the gun module 31. It is important to provide such thermal isolation after the firing of a burst. During firing the flow rates of the liquid propellant are normally high enough to provide sufficient cooling. Thus, while the FIG. 3A embodiment of the present invention discloses retraction after each individual firing, it should be recognized that it might be desirable in some instances to retract the entire injection mechanism only after the firing of a burst as in the FIGS. 17 and 17A embodiment.

In some instances, it may be desirable to include a low conductivity thermal barrier between the barrel and the receiver to further reduce the possibility of transfer of heat to the propellant after the firing of a burst.

A schematic diagram of the hydraulic drive control system for the gun module 31 as shown in FIGS. 14A and 14B. Pressurized hydraulic fluid for driving the various actuators is brought into the system through a line 191. The motor for producing this pressurized hydraulic fluid is preferably separate from the gun itself so that the gun can be kept light in weight and small in profile.

If the gun is installed in an aircraft the source of the pressurized hydraulic fluid can be the hydraulic system of the aircraft.

One of the features of a hydraulic control system is fast response. In the present invention the first shot is made at full cyclic rate.

The hydraulic fluid is returned from the control system to the source by a line 193.

The control system includes a bias control valve indicated generally by the reference numeral 195. The bias control valve is an on-off valve and is controlled by a trigger solenoid 197. The trigger solenoid 197 is shown in the "on" position in FIG. 14.

The bias control valve 195 includes a housing 199 and a valve spool 201 reciprocable within a bore in the housing 199.

Pressurized fluid flows into the housing 201 through an inlet conduit 203.

Outlet conduits 205 and 207 lead from the valve housing 199 to a housing 209 forming a part of the misfire detector mechanism 113. Outlet conduits 211 and 213 extend from housing 199 downward to other conduits which are connected to ports at opposite ends of the various control valve housings. Outlet conduits 215 and 217 connect with the return conduit 193.

Lands 219 and 221 on the spool of the bias control valve control the flow through the various conduits.

The valve spool 201 includes a cam follower 220 which engages a trace 222 in the cam 49 in the armed condition of the system with the trigger solenoid in the off position. When the trigger solenoid is energized to the on position, the cam follower remains in the cam trace 222 until a cross-over path 224 permits the cam follower to shift to the trace 226. This insures that the trigger solenoid will move the valve spool 219 to the on position in the proper time sequence with the other components of the hydraulic control system.

The valve housing 209 of the misfire detector mechanism 113 has a valve spool 223 mounted for reciprocation within the housing and connected to the rod 127. Outlet conduits 225 and 227 extend downward from the housing 209. Flow from the inlet conduit 191 and to the outlet conduits 225 and 227 is controlled by lands 229 and 231 on the valve spool 223. The conduit 225 contains an orifice 233.

A spring 235 acting on the backface of the land 231 biases the spool 223, and the rod 127, in a forward direction.

Pressurized fluid, conducted through the housing 209 by the conduit 207, acts on a forward face of a land 237 to bias the spool 223 in a rearward direction.

A cam follower 239 is connected to the rearward extension of the valve spool 223 and is normally engaged in a trace 241 of the cam 49. The cam trace 241 extends around the outside circumference of the cam 49 and parallel to a second cam trace 243. A path 245 connects the traces 241 and 243.

As will be described in greater detail below in the description of the operation of the gun, the cam follower 239 remains in the trace 241 so long as a misfire does not occur. The pressure developed within the bore 123 of the housing 115 at the end of the barrel during cyclic firing is sufficient to keep the piston 125 forward, as illustrated, when the path 245 is aligned with the cam follower 239. However, if a misfire occurs, there is insufficient pressure in the chamber 121 behind the piston 125, and the force developed by the pressurized hydraulic fluid acting on the forward face of the land 237 shifts the valve follower 239 from the trace 241 through the path 245 and into the trace 243; and the cam follower 239 thereafter remains in the trace 243. This cuts off the flow of fluid through the conduit 227 and transmits pressurized hydraulic fluid through the conduit 225 by shifting the land 229 to the other side of conduit 191.

The phantom outline shows the cam follower 239 shifted to the trace 243.

In the misfire condition, the bolt 55 and injector 63 will remain locked in the forward position as illustrated. This mode of operation will be further described with reference to the cam traces shown in FIGS. 16 and 18 below.

The angle of the cam path 245 is such that the cam follower 239 will remain in the path 243 because of the direction of rotation of the cam 49. The valve spool 223 will thus remain in the rearward position illustrated by the phantom outline against the bias of the spring 235.

The conduits 211 and 213 extend from the bias control valve 195 down to a bolt and injector system control valve indicated generally by the reference numeral 247.

The control valve 247 includes a valve housing 249. The valve housing 249 has a longitudinally extending central bore 251.

A compound spool is axially shiftable within the bore 251.

The compound spool includes an inner spool 253 and a sleeve 255. The sleeve 255 is axially shiftable on the reduced diameter central portion of the spool 253 between abuttment stops 257 and 259 at opposite ends of the spool 253.

The conduit 211 connects to the forward end of the housing 249 and the conduit 213 connects to the rearward end of the housing 249. When pressurized fluid is supplied through the conduit 211 as illustrated in FIG. 14B the sleeve 255 is shifted rearward and into engagement with the stop 259.

A cam follower 261 on the valve spool 253 rides in a trace 263 on the main cam 49. Rotation of the cam 49 periodically shifts the cam follower 261 forward to the position indicated by the dotted line to cause corresponding shifting of the valve spool 253 and the sleeve 255 engaged with stop 259.

Pressurized fluid is led into the control valve 247 by the conduit 227.

Conduits 262 and 265 extend from the valve housing 249 to the rear ends and to the front ends respectively of the actuators 83 and 68 for the bolt 55 and the yoke 61 of the propellant injection mechanism.

With the cam 49 in the position illustrated and the valve sleeve 255 pressed against the stop 259 of the spool 253, the pressurized fluid flows from the conduit 227 past a land 267 and to the conduit 262 and the back sides of the actuators 83 and 68. The respective pistons and the actuators are thus forced forward to the positions illustrated in FIG. 14B.

When the cam 49 rotates to a position in which the trace 263 shifts the cam follower 261 to the dotted line position shown in FIG. 14B the land 267 closes off flow through the conduit 262 and directs the flow to the conduit 265 to reciprocate the pistons in the bolt actuator 83 and the propellant injection actuator 68 to the rear.

In this mode of operation the control valve 247 acts as an on-off valve or flow switching valve to cause reciprocation of the bolt and propellant injection mechanism with the movement of the cam follower 261. Conduits 269 and 271 extend downward from the valve housng 249 and connect with the return conduit 193. Flow through these conduits 269 and 271 is controlled by lands 273 and 275 on the valve sleeve 255. These lands open one side of each of the actuators 83 and 68 to hydraulic fluid return when the other side of each actuator is being pressurized.

Pressurized hydraulic fluid is supplied through the conduit 213 to shift the sleeve 255 forward against the stop 257 when the gun is placed in the armed condition (a condition in which the main cam drive motor is energized, the main cam is rotating and hydraulic power is applied to the gun module) and the trigger solenoid 197 is in the off position. In this condition of operation the reciprocation of the spool 253 by the cam trace 263 is not effective to produce any reciprocation of the bolt and propellant injectors. Instead, pressurized hydraulic fluid is continuously transmitted from the conduit 227 to the conduit 265 past the land 267 and to the forward end of the actuators 83 and 68. The bolt and propellant injectors are thus held in the open position ready to start firing as soon as the trigger solenoid 197 is energized to the on position.

As illustrated in FIG. 14A the hydraulic drive control system includes a breech lock control valve indicated generally by the reference numeral 277 and a projectile loader control valve indicated generally by the reference numeral 279.

These control valves control the breech lock actuator 163 and the projectile loader actuator 112.

The control valves 277 and 279 are compound spool control valves like the bolt and injector control valve 247 and operate in a dual mode like the control valve 247.

Thus, a conduit 211 is connected to the forward end of a valve housing 281 of the control valve 277 and the conduit 211 is also connected to the forward end of a valve housing 283 of the control valve 279.

A conduit 213 is connected to the rearward end of the housing 281 and a rearward end of the housing 283. Pressurized hydraulic fluid is supplied to a central part of each valve housing 281 and 283 by the conduit 227 during normal operation.

The pressurized fluid from the line 227 is directed alternately to the front and to the back side of the breech lock actuator 167 through conduits 285 and 287.

The breech lock control valve 277 includes a compound spool. The compound spool has an inner spool 289 and a valve sleeve 291. The valve sleeve 291 is shiftable on the spool 289 between the stops 293 and 295.

A land 297 controls the fluid from conduit 227 to the conduits 285 and 287.

On a misfire, pressurized fluid from the main hydraulic line 191 is directed to the conduit 225 (see FIG. 14B), through an orifice 233, and, in the case of the breech lock actuator 163, through a conduit 299 and a one-way check valve 301 to the front end of the housing 167 to hold the breech lock in the locked position illustrated.

During normal cyclic firing operation pressurized hydraulic fluid is supplied to the front end of the housing 281 of the breech lock control valve to position the sleeve 291 against the stop 295 as illustrated in FIG. 14A.

A cam follower 303 on the valve spool 289 rides in a trace 305 on the cam 49. As the cam 49 rotates, the trace 305 periodically shifts the cam follower 303 to the forward position illustrated by the dotted outline. This in turn shifts the valve spool 289 and the vlave sleeve 291 to produce reciprocation of the piston 168 in the breech lock actuator. Conduits 307 and 309 connect the valve housing 281 with the return line 193.

If the trigger off but armed condition pressurized hydraulic fluid is directed through the conduit 213 to the rear face of the sleeve 291 to move the sleeve forward against the stop 293. In this condition of operation, the breech lock actuator is maintained in the unlocked position ready for the start of firing. The reciprocation of the valve spool 295 by the cam follower 303 is not effective to change the flow of pressurized hydraluic fluid from the conduit 287 to the back side of the piston 169.

The conduit 227 includes a one-way check valve 311 and the conduit 309 includes a one-way check valve 313 for preventing bleed-off of pressure from the front part of the hydraulic actuator 167 during a misfire con-

dition in which the breech lock is maintained in the locked position.

The projectile loader control valve 279 includes an inner valve spool 315 and a valve sleeve 317. The valve spool 315 has stops 319 and 321 at opposite ends of the valve spool. A cam follower 323 rides in a trace 325 on the cam 49 and is shiftable between the solid line position and the dotted line position shown to reciprocate the valve spool 315.

Pressurized hydraliuc fluid supplied to the forward end of the valve housing by the conduit 211 during normal cyclic firing operation shifts the valve sleeve 317 rearward against stop 321 as illustrated.

Pressurized hydraulic fluid supplied through the conduit 213 to the rearward end of the valve housing 283 shifts the valve sleeve 317 forward against the stop 319 during the armed but non-firing condition of the gun.

Pressurized hydraulic fluid from the conduit 227 flows past a one-way check valve 327 and into the central part of the bore within the housing 283. From there the pressurized fluid flows either through a conduit 329 to the rearward end of the projectile loader actuator or through a conduit 331 to the forward end of the projectile loader actuator 112. The flow of pressurized fluid through the conduit 329 and 331 is controlled by a land 333 on the sleeve 317. Fliuid is returned to the return line 193 from the housng 283 by conduits 335 and 337. The conduit 335 contains a one-way check valve 339.

A conduit 341, having a one-way check valve 343 connects the forward end of the actuator 112 with the conduit 225. When the misfire detection mechanism directs pressurized fluid through the conduit 225 to the projectile loader actuator 112, the actuator is moved rearward to hold the projectile loader in an open position.

It is an important feature of the present invention that several of the controlled elements are interlocked through the cam to the control valve controlling these components.

Thus, both the bolt and the propellant injectors are interlocked through the cam to the bolt and injector control valve. This insures precise phase relationship between the control valve and the actuators and also precise phase relationship between actuated components. Because hydraulic boost is used for actuation, cam face loadings are quite low. And because of the interlock a simple on/off flow switching valve can be used without the need for expensive and complex feedback mechanisms of conventional hydraulic serve motor systems.

As illustrated in FIG. 14B, the cam follower 87 of the bolt 55 rides in a trace 345 during normal cyclic firing of the gun. As best shown in FIG. 18 this trace 345 is located on the inner periphery of the cam and accommodates the reciprocatory motion of the bolt.

The cam follower 89 of the propellant injection mechanism rides in a trace 347 during normal cyclic firing of the gun.

The spark plug cam follower 91 rides in a trace 349 during normal cyclic firing of the gun.

The traces 345, 347 and 349 connect with straight through traces 351, 353 and 355 respectively as illustrated in FIG. 18. These straight through traces are the traces in which the cam followers ride during the open bolt static condition after the gun has been armed but beore the trigger solenoid 197 has been moved to the on position to initiate firing.

The traces 345, 347 and 349 also connect with additional straight through traces 357, 359 and 361 respectively as illustrated in FIG. 18. These last three straight through traces provide the paths for the respective cam followers in the closed bolt or misfire condition of operation.

The cam 49 is rotated in the direction indicated in the drawings by a hydraulic motor or other suitable drive means engaged with the gear teeth 53.

The operation of the gun module 31 will now be described. The mechanical operation of the gun will be described first, and the operation of the hydraulic control circuit will then be summarized.

The following is a description of the operation of the gun mechanism.

When the gun is placed in the armed position, the main cam drive motor (not shown in the drawings) is energized and hydraulic power is supplied to the gun module through the main hydraulic supply line 191.

If the trigger is in the off position, the hydraulic control system (shown in FIGS. 14A and 14B) will unlock the breech lock 165 and will position the projectile loader lever in the up position. The bolt 55 and the injector yoke 61 will be positioned in the rear position. As long as the gun is in the armed condition with the trigger off these components will remain in these positions. This is generally referred to as the open bolt position.

When the trigger solenoid 197 is put into the on position, the hydraulic control system and main cam 49 will cover the following sequence of events:

1. The projectile loader lever 109 moves down, forcing a new projectile 105 into the loading tray 111.
2. The bolt 55 moves forward, ramming the projectile 105 into the combustion chamber 57. When the bolt 55 is fully forward, the breech lock 165 is locked.
3. The injector pistons 63 and 65 initially move forward with the bolt 55. However, until the bolt 55 stops, there will be no relative movement between the injector pistons 63 and 65 and the bolt 55. When the bolt 55 stops, the injector pistons 63 and 65 continue to move forward, injecting a charge of fuel and acid through the pre-combustion chamber 73 and then into the combustion chamber 57. The injected propellant will force the projectile 105 forward as it is injected. Since the diameter and stroke of the fuel and acid pistons 65 and 63 are constant, each forward motion of the injectors will meter a fixed propellant charge with a constant, predetermined mixture ratio.
4. When the injector pistons 63 and 65 are fully forwad and the injection is completed, the spark plug 79 is moved forward sealing off the injection ports 71 and 72. It should be noted at this point that in the case of the mono-propellant, metering of the propellant can be accomplished without the need for a cut-off valve. In the case of a mono-propellant, it is often possible to use tank pressure without a hydraulic boost for injecting the propellant into the firing chamber. The injection of the mono-propellant can start by putting the fuel into the chamber behind the projectile simply by opening a valve. The mono-propellant continues to flow

into the combustion chamber behind the projectile until the resistance to continued forward movement of the projectile produced by the forcing cone is greater than the force developed by the pressurized fuel on the back face of the projectile. At that point the projectile stops and a metered amount of propellant is in the firing chamber.

5. When the spark plug 79 is full forward, electrical power is supplied to the spark plug; and the gun is fired.
6. The breech lock 165 is then unlocked.
7. The projectile loader lever 109 moves to the up position.
8. The bolt 55 and injector pistons are driven to the rear. when the rewarward movement of the bolt 55 stops, the rearward movement of the injector pistons 63 and 65 continues for the length of the stroke of the pistons. As the pistons move to the rear, propellant, (i.e., acid and fuel) flows through the ball check valves 75 and 77 and fills the volumes created by the rearward movement of the pistons relative to the bolt. The pistons are, in effect, drawn backwards through the propellant to fill the injector cylinders during retraction of the pistons. This is the charge that will be injected into the firing chamber 57 for the next round.
9. The next firing cycle is then repeated.
10. In the event of a misfire, the misfire detection mechanisms 113 and module shutdown valve 223 will shut off the hydraulic supply (see the hydraulic control circuit of FIGS. 14A and 14B). The breech lock 165 will be locked, the projectile loader lever 109 will go to the up position, and the bolt 55 and injector pistons 63 and 65 will be forced to the forward position. The misfired module will remain in the shutdown position until maintenance can be performed. However, the other modules of the gun cluster remain in operation.

The operation of a hydraulic control circuit is believed to be evident from the detailed description of FIGS. 14A and 14B above but will now be summarized.

The hydraulic control circuit illustrated in FIGS. 14A and 14B has three basic elements. The basic elements of the circuit are:

1. The primary control components. These components include the misfire detection mechanism 113 and the module shutdown valve 223. The primary control components also include the bias control valve 195.
2. The secondary control components. The secondary control components include the bolt and injector system control valve 247, the projectile loader control valve 279 and the breech lock control valve 277.
3. The auxiliary control components. The auxiliary control components include the gun purge valves 141 and 143 and the three-way time delay valve 161 and the valve actuator 153.

The primary control components consist of the misfire detection mechanism 113 and the module shutdown valve 223 and the bias control valve 195. The bias control valve 195 is operated by the electrical solenoid 197, which in turn is controlled by the gun trigger. The bias control valve 195 controls the hydraulic fluid supply to the secondary control valves.

The design and operation of the secondary control valves is a unique feature of the present invention and is fundamental to the operation of the hydraulic control circuit. The bolt and injector system control valve 247 is typical of the secondary control valves. The valve 247 consists of the outer valve body 249, the hydraulically operated sleeve 255 and the cam-operated inner spool 253. The cam follower 261 attached to the rear end of the spool 253 engages the groove 263 of the cam 49. As the cam 49 rotates, the spool is caused to translate forward and rearward in the outer valve body. The spool is shown in FIG. 14B in its rear position (the dotted line illustrates the maximum forward position of the cam follower). The sleeve 255 is concentric to the spool and its position relative to the spool is controlled hydraulically by means of the bias control valve 195. Hydraulic pressure applied to the front end of the sleeve 255 will force the sleeve rearward against the rear stop 259 of the spool 253, and hydraulic pressure applied to the rear of the sleeve 255 will force the sleeve forward against the forward stop 257 of the spool. In either the forward or the rear position relative to the spool, the sleeve will translate forward and rearward in the outer valve body 249 as the piston moves. The position of the sleeves with respect to the spool in each of the secondary control valves 247, 277 and 279 is controlled by means of the bias control valve 195, which, in turn, is actuated by the trigger solenoid 197. When the trigger solenoid 197 is energized, the bias control valve 195 is pulled to the rear, thus allowing hydraulic fluid to flow to the forward end of all of the secondry control valves. This forces the sleeves rearward against the rear stops of the related spools. When the trigger solenoid 197 is deenergized, the trigger solenoid during spring 196 pushes the bias control valve forward. This allows hydraulic fluid to flow to the rear end of all the secondary control valves and forces the sleeves forward against the forward stops of the related spools.

The relative positions of the various components in respect to the cam follower and sleeve position are tabulated in the following table I.

TABLE I

BOLT, INJECTOR, BREECH LOCK, AND PROJECTILE LOADER POSITIONS AS A FUNCTION OF SLEEVE* AND CAM* POSITION

Sleeves	Forward (trigger off)	Rear (trigger on)	
	forward		
Cam follower Position ff of rear		rear	
Bolt and bolt actuator	rear	forward	rer
Injector and injector a ctuator	rear	forward	rear
Breech lock actuator	forward	rear	forward
and breech lock	unlocked	locked	unlocked
Projectile loader actuator	rear	forward	rear
and projectile loader lever	up	down	up

* Sleeves and cam followers on bolt and injector valve, breech lock control valve and projectile loader control valve

When the trigger is in the off condition, the bias valve 197 is forced forward by a bias control spring 196. Hydraluic fluid flows to the rear of each of the secondary control valves 247, 277 and 279, thus forcing the sleeves into the forward position. With the sleeves in the forward position, the bolt and injector control valve 247 will allow hydraulic fluid to flow to the forward port of the bolt actuator 83 and to the forward port of the injector actuator 69, thus forcing the bolt 55 and

the injector pistons 63 and 65 to the rear. The breech lock control valve 277 allows hydraulic fluid into the rear chamber of the breech lock actuator 167 which forces the breech lock forward into the unlocked position.

The projectile loader control valve 279 allows hydraulic fluid to flow into the forward chamber of the projectile loader actuator 112, forcing it rearward and causing the projectile loader lever 109 to move into the up position. As the cam 49 rotates, the cam followers and systems of all the secondary control valves 247, 277 and 279 will translate forward and backward. The sleeves will translate with However. piston. However in this trigger off condition, the valve ports are arranged so that the bolt 55, injector pistons 63 and 65, projectile loader lever 109, and breech lock 165 wil remain in position as the sleeves translate.

When the trigger is energized or on, the bias control valve 195 moves rearward, and hydraluic fluid flows to the forward chambers of the secondary control valve 247, 277 and 279 forcing the sleeves to the rear. The sleeves will translate with the valve spools as the main cam 49 rotates. However, with the sleeves in the rear position, the valve ports are arranged so that the following is accomplished:

In the bolt and injection control valve 247, with the sleeves positioned to the rear, translation of the spool 253 and the sleeve 255 forward as the main cam 49 rotates allows hydraulic fluid to flow to the forward chamber of the bolt actuator 83 and the injector actuator 68, thus forcing the bolt 55 and the injector pistons 63 and 65 to the rear. Translation of the spool 253 and sleeve 255 rearward allows hydraulic fluid to flow to the rear chamber of the bolt and injector actuators, thus forcing the bolt and injector piston forward.

In the breech lock control valve 277 with the sleeves 291 in the rear position, translation of the sleeve 291 and spool 289 forward as the main cam 49 rotates allows hydraulic fluid to flow into the rear chamber of the breech lock actuator 163, forcing it forward and unlocking the breech. Translation of the sleeve and spool to the rear allows hydraulic fluid to flow into the forward chamber of the breech lock actuator 163, forcing it rearward and locking the breech.

In the projectile loader conrol valve 279 with its sleeve 317 in the rear position, translation of the sleeve 317 and spool 315 forward as the main cam 49 rotates allows hydrauiic fluid to flow to the forward chamber of the projectile loader actuator 112 forcing the actuator rearward and positioning the projectile loader lever 109 in the up position. Translation of the sleeve and spool to the rear allows hydraulic fluid to flow to the rear chamber of the projectile loader actuator 112 forcing it forward and positioning the projectile loader lever into the down position.

Sequencing of the movement of the bolt 55, injector piston 63 and 65, breech lock 165 and the projectile loader lever 109 are controlled by the design of a main cam 49. One revolution of the main cam 49 will result in one cycle of operaton of the bolt, injectors, breech lock and projectile loader with trigger in the on position.

The other primary control components are a misfire detection mechanism 113 and a module shutdown valve 223. The main function of the module shutdown valve 223 is to shut off hydraulic supply in the event of a misfire. A cam follower 239 is attached to the rear end of the valve 223 and engages one of two grooves or traces 241 and 243 in the main cam 49. The normal position of the misfire detection mechanism and module shutdown valve is when the cam follower engages its forward trace 241, or the valve 223 in the forward position or open position. The valve is acted upon by several forces, depending on the control mode.

In the trigger off (bias control valve 195 in the forward position) condition, hydraulic fluid is allowed to flow into the spring chamber 235 of the misfire detection module shutdown system valve. The combination of the spring and the hydraulic pressure forces the valve to remain in the forward position with the cam follower 239 engaged in the forward cam trace 241.

In the trigger on (bias control valve 195 in the rear position) condition, hydraulic fluid flows into the rear chamber, acting on the rear piston 237 and exerting a force rearward on the valve 223. However, during normal firing, high pressure propellant gases are bled into the gas chamber 121 which exert a force to maintain the valve 223 in the forward position. The combination of the bleed gas pressure and spring exert a greater force than the hydraulic force so that valve stays in the forward direction.

In the event of a misfire, there will be no propellant gas pressures generated. The hydraulic fluid pressure in the rear chamber of the housing 209 acting on the rear piston 237 will overcome the force of the spring 235 and will exert a net rearward force. As the main cam 49 rotaes around, the cam follower 239 will engage the transfer groove or path 245 and will move rearward to engage the rear groove or trace 243. The misfire detection and module shutdown valve 223 will be forced to the rear and will remain in this position. In moving to the rear position. the valve will shut off the primary hydraulic flow from the conduit 191 to the bias control valve 195, the bolt and injector control valve 247, the breech lock control valve 277 and the projectile loader control valve 279. The shutdown hydraulic circuit is opened, and hydraulic fluid will flow through the restricting orifice 233 and through the check valve 30[illegible] to the forward end of the breech lock actuator 163 and through the check valve 343 to the forward end of the projectile loader actuator 112. The breech lock actuator 163 is forced to the rear into the locked position The projectile loader actuator 112 is also forced to the rear. Hydraulic fluid also flows through the three-way time delay valve 161 and forces the purge valve piston yoke 147 forward, opening the chamber purge valves 141 and 143. Fuel (which may be JP-4 in the case of an aircraft installation) or other fluid (such as water) from the purge supply will flow through the chamber and out to the purge sump, flushing the propellant charge out of the firing chamber 57. After a suitable time delay, the three-way valve 161 will bypass the hydraluic fluid to the return line 193, and the purge valve spring 157 will force the purge valve piston to the rear closing the chamber purge valves.

In the misfire, condition, the bolt 55 and the injector piston 65 will remain locked in the forward position, and the gun module 31 will shutdown until serviced.

While we have illustrated and described the preferred embodiments of our invention, it is to be understood that these are capable of variation and modification, and we therefore do not wish to be limited to the precise details set forth, but desire to avail ourselves of

such changes and alterations as fall within the purview of the following claims.

We claim:

1. A gun of the kind in which liquid propellant is burned in a firing chamber to fire a projectile from the gun and including, a barrel, a receiver, a bolt, means for reciprocating the bolt in the receiver, a firing chamber, injection mechanism for injecting a non-hypergolic bi-propellant liquid propellant into the firing chamber on each cycle of reciprocation of the bolt, said injection mechanism including a separate injector for each component of the bi-propellant, each said injector comprising a chamber and a piston of predetermined dimensions, means rigidly interconnecting said pistons, actuator means for moving the interconnected injector pistons as a unit whereby said predetermined dimensions and common actuator establish accurate metering and a constant mix of the bi-propellant injected directly into the firing chamber to fully occupy said chamber, igniter means for igniting the non-hypergolic bi-propellant in the firing chamber and control means effective to actuate the igniter means to ignite the propellant after the injection mechanism has filled the firing chamber with the non-hypergolic bi-propellant mix.

2. A gun as defined in claim 1 wherein the actuator means include a motor powered by a source of fluid separate from the gun.

3. A gun as defined in claim 2 including a control valve for each motor, each said control valve having a control element driven by a cam follower, and a rotatable cam engaged to provide cam control and fluid actuator drive for the injection mechanism by each said follower.

4. A gun as defined in claim 3 wherein said motor includes a movable element including a cam follower and wherein the cam has a trace engaged by a respective control element cam follower and has a second trace engaged by the movable element of the motor to insure a precise phase relationship between the control valve and the motor.

5. A rapid firing gun of the kind in which liquid propellant is burned in a firing chamber to fire a projectile from the gun said gun comprising, a barrel, a receiver, a bolt, bolt actuator means for reciprocating the bolt within the receiver, a combustion chamber having wall structure of substantial mass subjected to heat soak produced during the rapid firing of a burst of projectiles from the combustion chamber, injection mechanism for injecting liquid propellant into the combustion chamber, said injection mechanism including a cylinder for containing the liquid propellant to be injected and a piston reciprocable within the cylinder to eject the propellant from the cylinder into the combustion chamber on each cycle of reciprocation of the bolt, mounting means mounting the injection mechanism for movement between a first, injection position in which the injection mechanism is physically connected to the combustion chamber for injecting liquid propellant into the combustion chamber and a second, isolated position in which the injection mechanism including the liquid propellant in the cylinder are physically separated from the wall structure of the combustion chamber to provide a thermal barrier to heat flow from the combustion chamber wall structure to the propellant, actuator means for moving the injection mechanism between the injection position and the isolated position, and valve means within the piston operable on retraction of the bolt to permit refilling of the cylinder piston assembly with propellant as the piston is moved rearward through the propellant within the cylinder after a firing of a projectile from the gun.

6. A hydraulically controlled gun of the kind in which liquid propellant is burned in a firing chamber to fire a projectile from the gun including, a barrel, a receiver, a bolt, a first hydraulic actuator for reciprocating the bolt within the receiver, a firing chamber, injection mechanism for injecting a liquid propellant directly into the firing chamber, a second hydraulic actuator connected to actuate the injection mechanism, cam means, a control valve for controlling movement of each said hydraulic actuator, a hydraulic circuit interconnecting a source of high pressure hydraulic fluid independent of the gun with said valve means and said actuators to power said hydraulic actuators under the control of the valve means, each said valve means having cam follower means engaging said cam means whereby the injection of said liquid propellant is coordinated with the reciprocation of said bolt.

7. A gun as defined in claim 6 wherein the liquid propellant is a mono-propellant.

8. A gun as defined in claim 6 wherein the liquid propellant is a non-hypergolic bi-propellant.

9. A gun as defined in claim 8 including actuators movable through relatively large distances for reciprocating the propellant injection mechanism and the bolt, cam followers movable through relatively small distances for controlling the actuators and wherein both the actuators and the cam followers are continuously engaged with the cam to insure a precise phase relationship between the actuators and the cam followers.

10. A rapid firing gun of the kind in which liquid propellant is burned in a combustion chamber to fire a projectile from the gun, said gun comprising, a barrel, a receiver, a bolt, bolt actuator means for reciprocating the bolt within the reciever, a combustion chamber having wall structure of substantial mass subjected to heat soak produced during the rapid firing of a burst of projectiles from the combustion chamber, injection mechanism for injecting liquid propellant into the combustion chamber, said injection mechanism including a cylinder for containing the liquid propellant to be injected and a piston reciprocable within the cylinder to eject the propellant from the cylinder into the combustion chamber on each cycle of reciprocation of the bolt, mounting means including a bore in the receiver separate from the bolt mounting the injection mechanism for movement between a first, injection position in which the injection mechanism including said cylinder is physically connected to the combustion chamber for injecting liquid propellant into the combustion chamber and a second, isolated position in which the injection mechanism including said cylinder and the liquid propellant in the cylinder are physically separated from the wall structure of the combustion chamber to provide a thermal barrier to heat flow from the hot combustion chamber wall structure to the propellant, and actuator means for moving the injection mechanism between the injection position and the isolated position.

11. A gun as defined in claim 10 including control means for the actuator means effective to retain the injection mechanism in the first, injection position during

the firing of a burst and to retract the injector mechanism in the bore to the second, isolated position only after the firing of a burst has been completed.

12. A rapid firing gun of the kind in which liquid propellant is burned in a combustion chamber to fire a projectile from the gun, said gun comprising, a barrel, a receiver, a bolt, means for reciprocating the bolt within the receiver, a combustion chamber having wall structure of substantial mass subjected to heat soak produced during the rapid firing of a burst of projectiles from the combustion chamber, injection mechanism for injecting liquid propellant into the combustion chamber, said injection mechanism including a cylinder for containing the liquid propellant to be injected and a piston reciprocable within the cylinder to eject the propellant from the cylinder into the combustion chamber, mounting means for the injection mechanism for movement between a first, injection position in which the injection mechanism is physically connected to the combustion chamber for injecting liquid propellant into the combustion chamber and a second, isolated position in which the injection mechanism and the liquid propellant in the cylinder are physically separated from the wall structure of the combustion chamber to provide a thermal barrier to heat flow from the hot combustion chamber wall structure to the propellant, and actuator means for moving the injection mechanism between the injection position and the isolated position, and wherein the mounting means mount the injection mechanism for reciprocation within the bolt and the injection mechanism is retracted to the second, isolated position with the retraction of the bolt after the firing of each round.

13. A rapid firing gun of the kind in which liquid propellant is burned in a combustion chamber to fire a projectile from the gun, said gun comprising, a barrel, a receiver, a bolt, bolt actuator means for reciprocating the bolt within the receiver, a combustion chamber having wall structure of substantial mass subjected to heat soak produced during the rapid firing of a burst of projectiles from the combustion chamber, injection mechanism for injecting liquid propellant into the combustion chamber, said injection mechanism including a cylinder for containing the liquid propellant to be injected, means for ejecting the propellant from the cylinder into the combustion chamber on each cycle of reciprocation of the bolt, mounting means including a bore in the receiver separate from the bolt mounting the injection mechanism for movement between a first, injection position in which the injection mechanism including said cylinder is physically connected to the combustion chamber for injection liquid propellant into the combustion chamber and a second, isolated position in which the injection mechanism including said cylinder and the liquid propellant in the cylinder are physically separated from the wall structure of the combustion chamber to provide a thermal barrier to heat flow from the hot combustion chamber wall structure to the propellant, and actuator means for moving the injection mechanism between the injection position and the isolated position.

14. A rapid firing gun of the kind in which liquid propellant is burned in a combustion chamber to fire a projectile from the gun, said gun comprising, a barrel, a receiver, a bolt, means for reciprocating the bolt within the receiver, a combustion chamber having wall structure of substantial mass subjected to heat soak produced during the rapid firing of a burst of projectiles from the combustion chamber, injection mechanism for injecting liquid propellant into the combustion chamber, said injection mechanism including a cylinder for containing the liquid propellant to be injected, means for ejecting the propellant from the cylinder into the combustion chamber, mounting means mounting the injection mechanism for movement between a first, injection position in which the injection mechanism is physically connected to the combustion chamber for injecting liquid propellant into the combustion chamber and a second, isolated position in which the injection mechanism and the liquid propellant in the cylinder are physically separated from the wall structure of the combustion chamber to provide a thermal barrier to heat flow from the hot combustion chamber wall structure to the propellant, and actuator means for moving the injection mechanism between the injection position and the isolated position, and wherein the mounting means mount the injection mechanism within the bolt and the injection mechansim is retracted to the second, isolated position with the retraction of the bolt after the firing of each round.

* * * * *

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Elmore et al.

[11] 3,803,975
[45] Apr. 16, 1974

[54] LIQUID PROPELLANT WEAPON

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[22] Filed: Sept. 13, 1971

[21] Appl. No.: 179,759

[52] U.S. Cl. 89/7, 89/194, 102/38
[51] Int. Cl. F41f 1/04
[58] Field of Search 89/1, 7, 26, 194; 102/38

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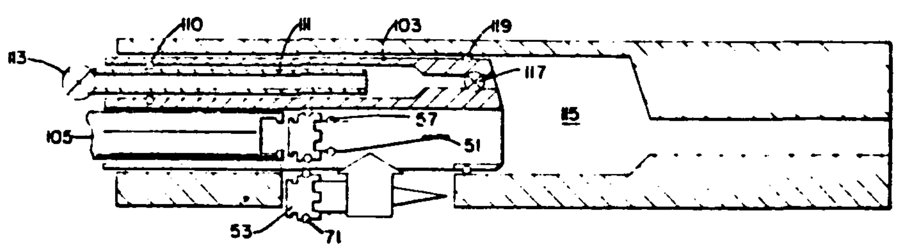
[57] ABSTRACT

A small bore liquid propellant weapon fires projectiles transported to the firing chamber in a projectile carrier. The projectile carrier is separated from the projectile just prior to firing the projectile. The projectile carrier can be reconnected with the projectile to extract the projectile from the weapon in the event of a misfire.

The small bore liquid propellant weapon has a reciprocating combustion chamber housing. The reciprocating combustion chamber housing forms a large diameter combustion chamber without ullage and eliminates a lock.

The small bore liquid propellant weapon includes an integral magazine which has its own pump for the liquid propellant. The magazine also has a valve element with high pressure seals that operate only for the life of the magazine and that are discarded with the empty magazine.

19 Claims, 27 Drawing Figures



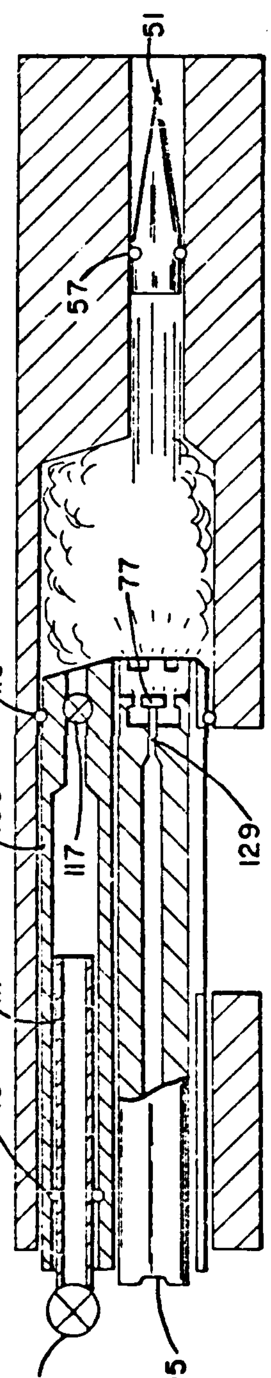


FIG_14

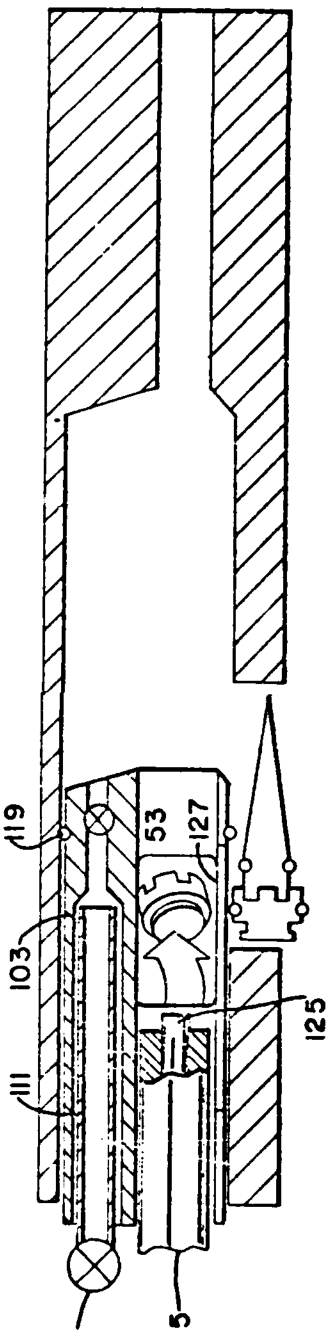


FIG_15

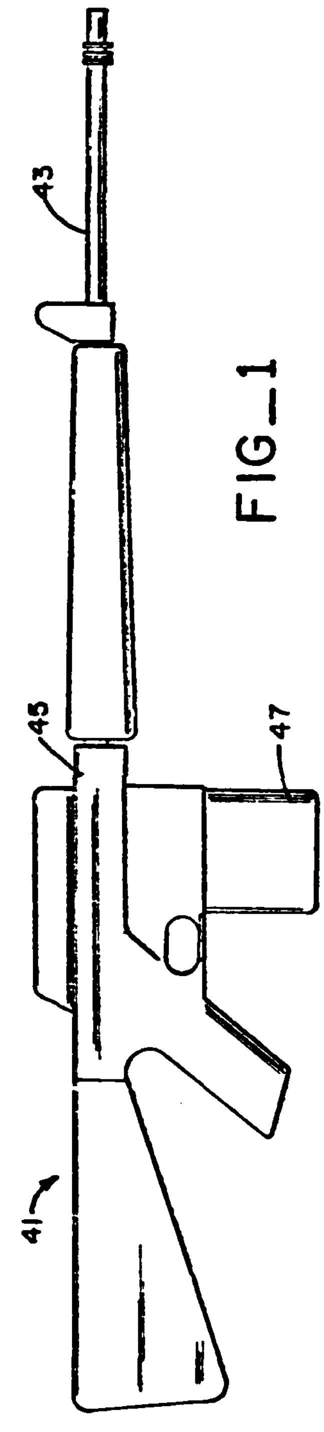


FIG_1

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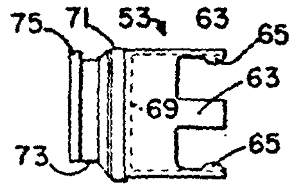

FIG_4

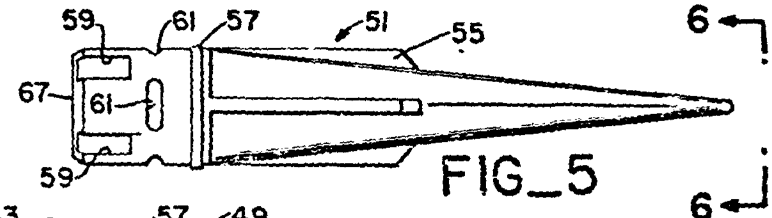

FIG_5

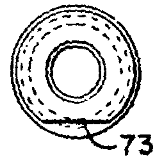

FIG_3

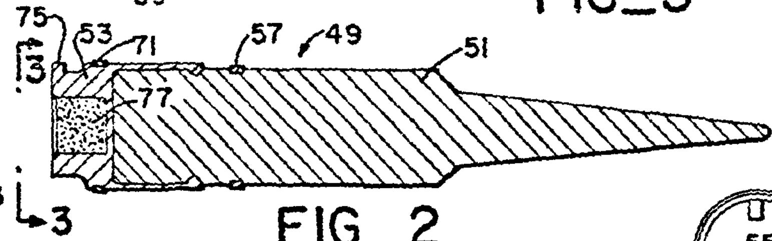

FIG_2

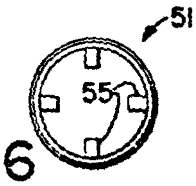

FIG_6

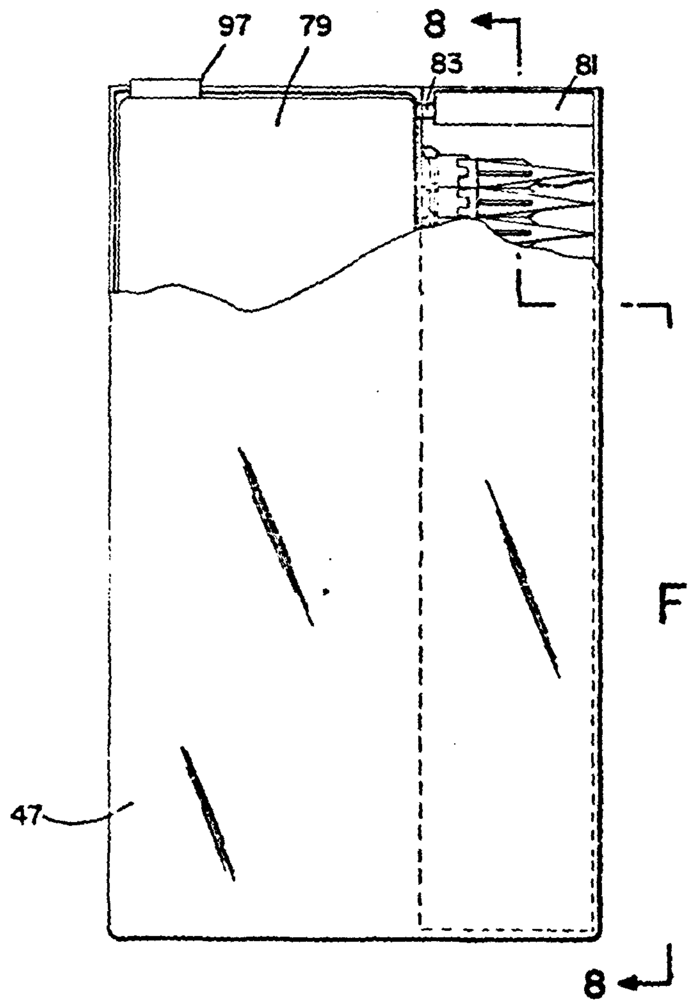

FIG_7

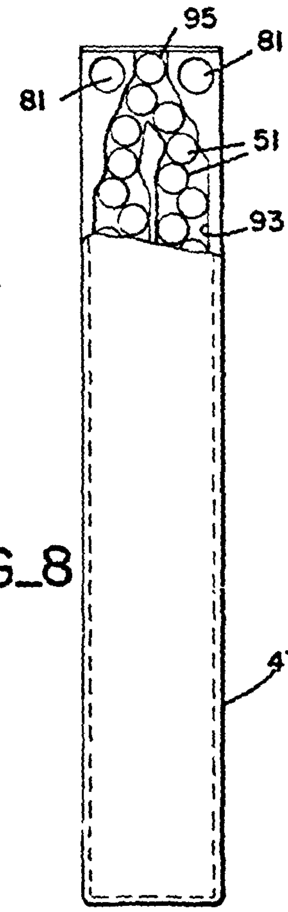

FIG_8

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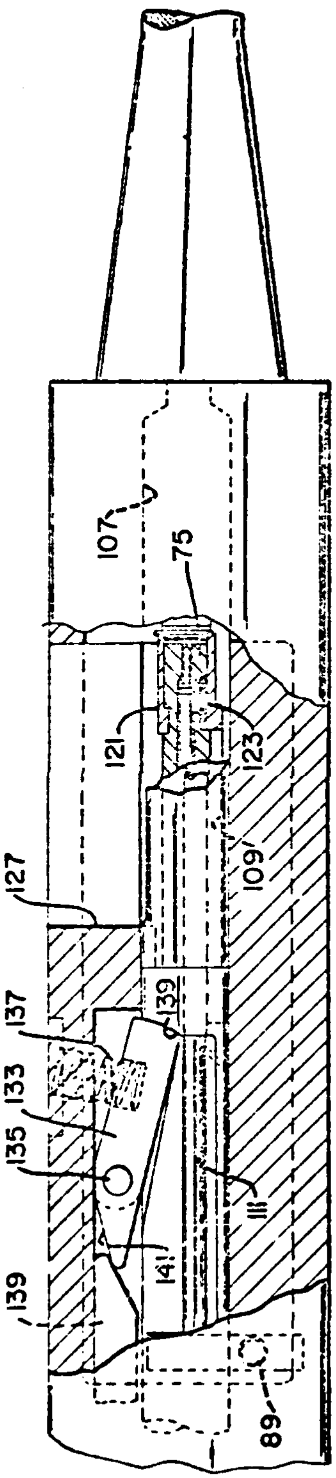

FIG_10

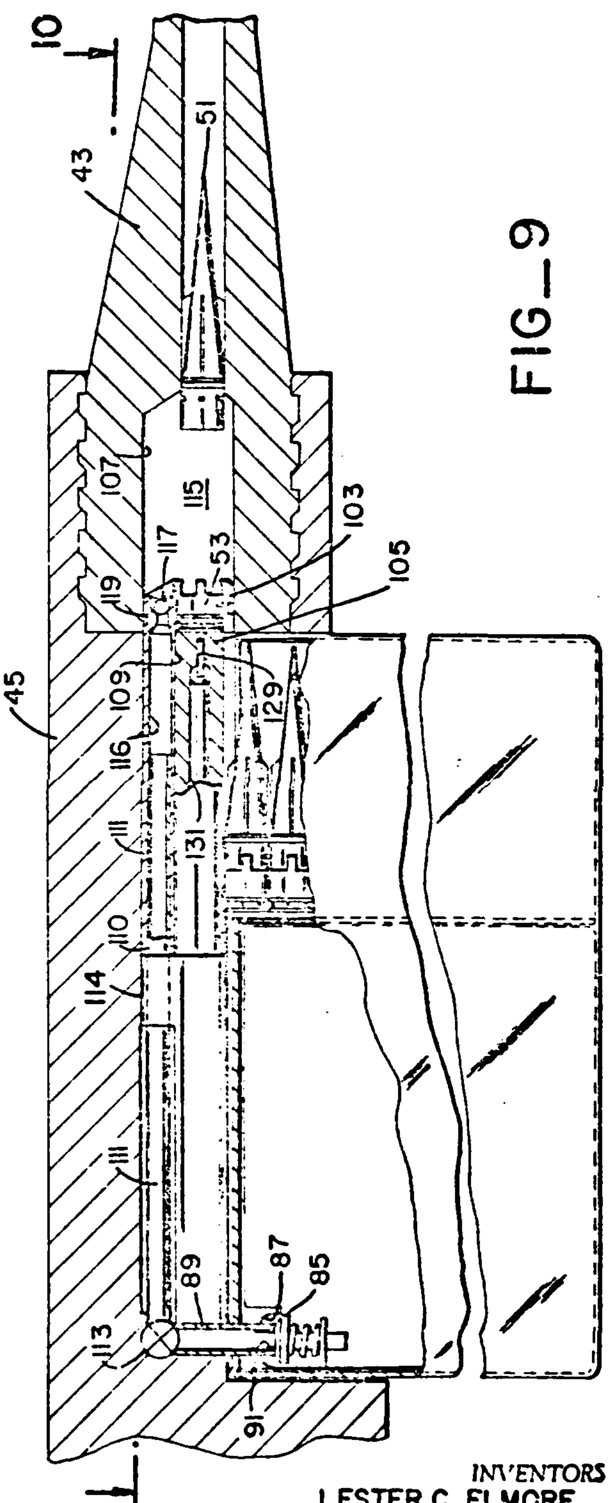

FIG_9

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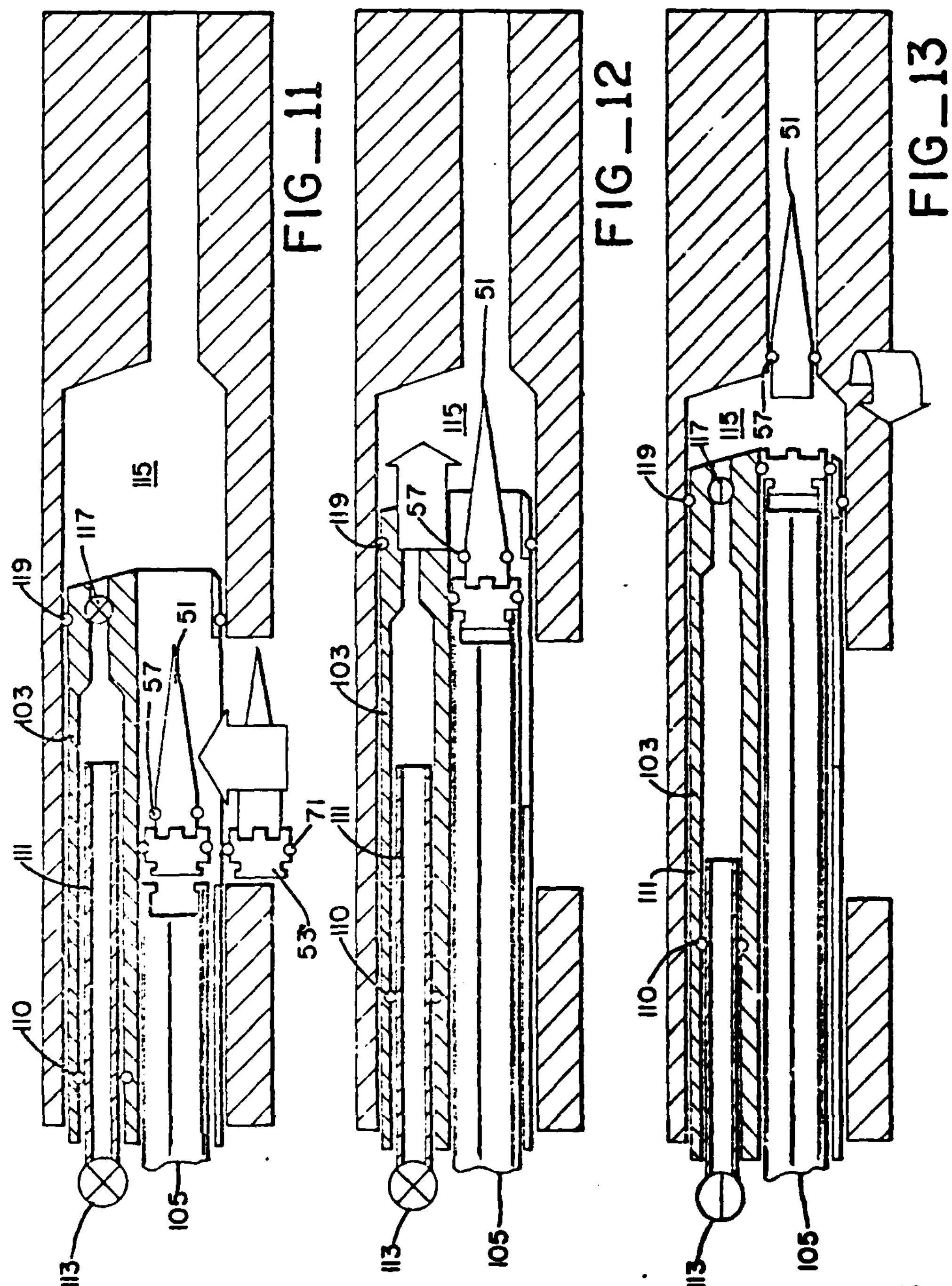

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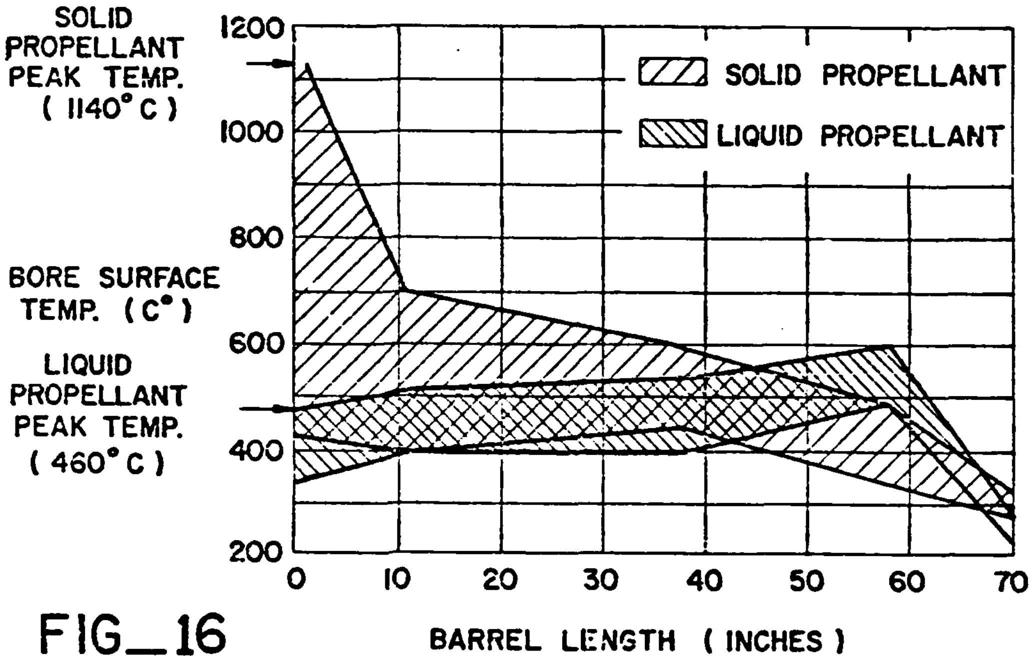

FIG_16

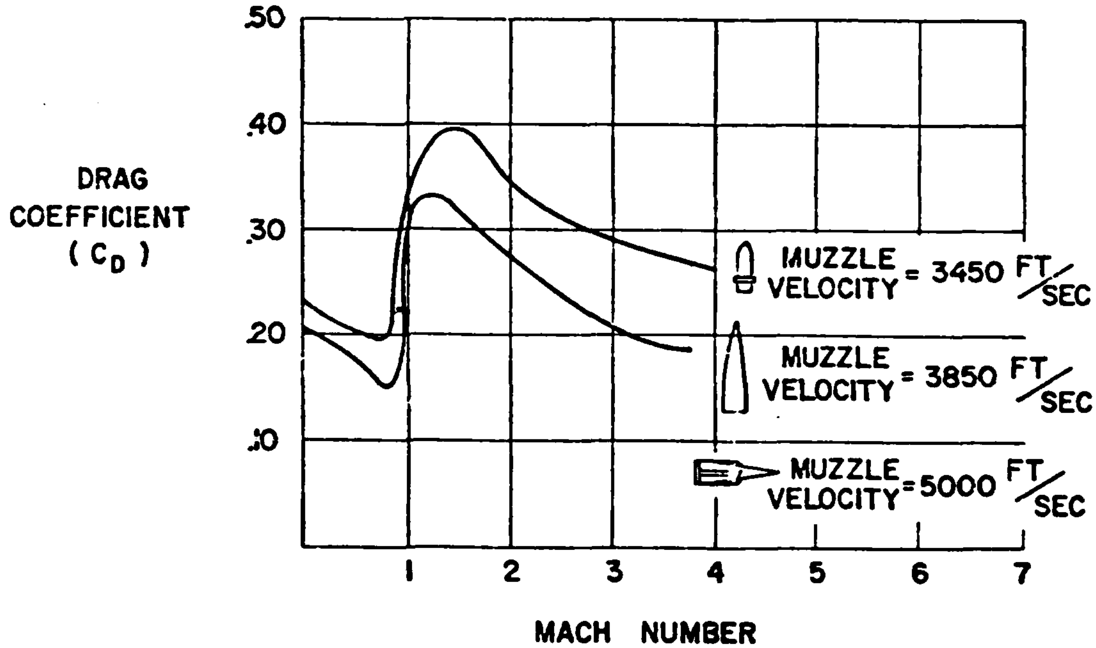

FIG_17

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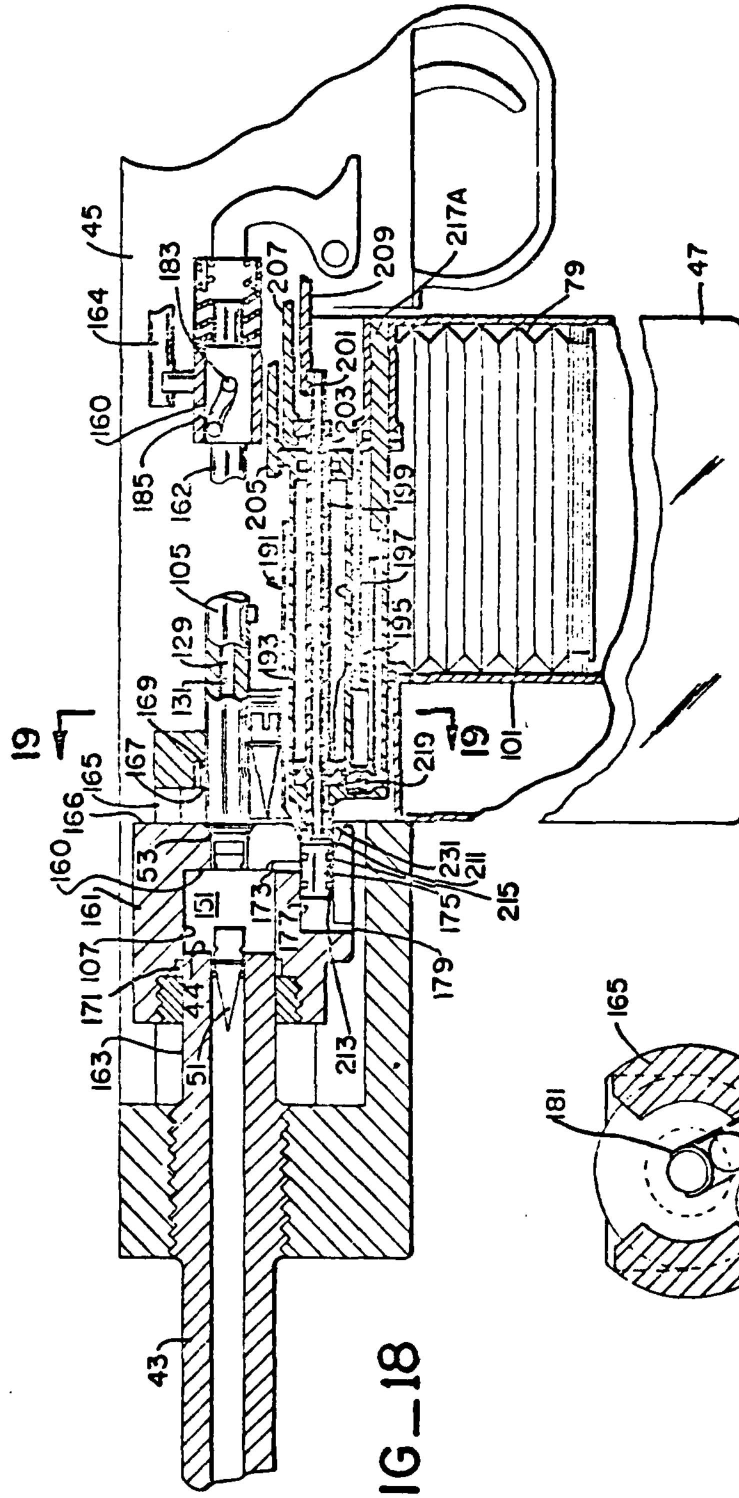

FIG_18

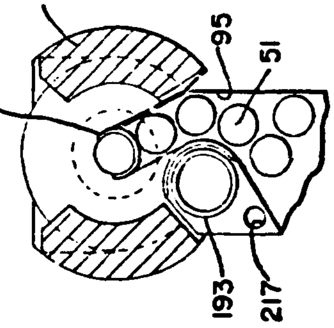

FIG_19

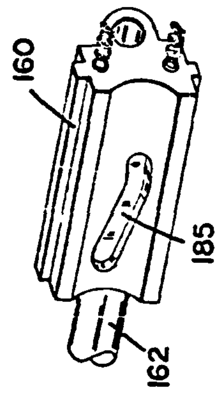

FIG_20

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PATENTED APR 16 1974 3,803,975

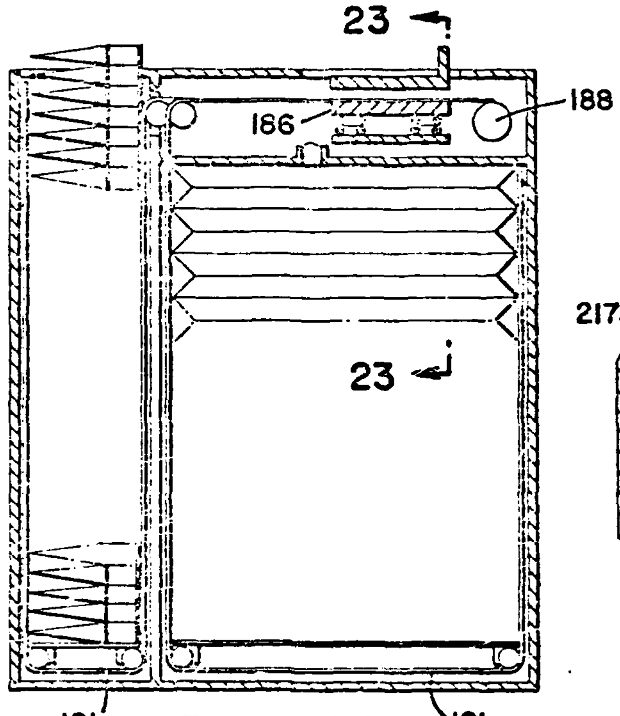

FIG_22

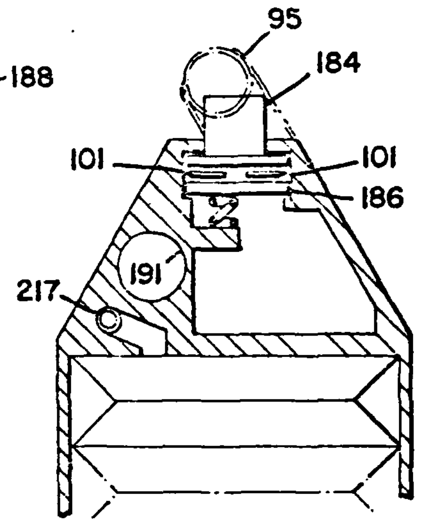

FIG_23

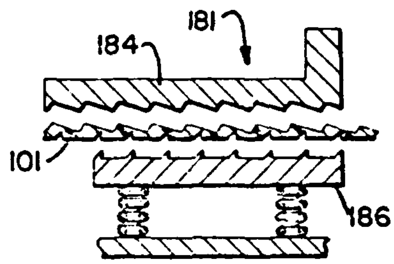

FIG_24

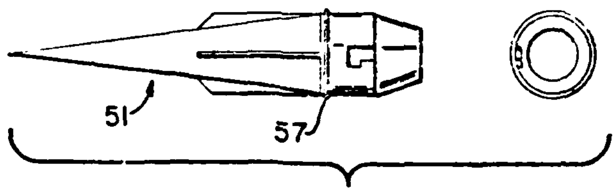

FIG_21A

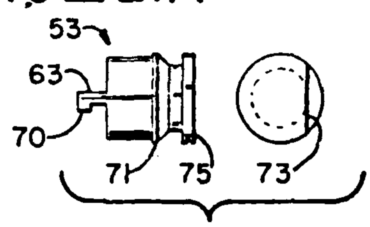

FIG_21B

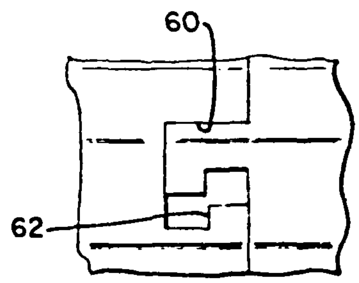

FIG_21D

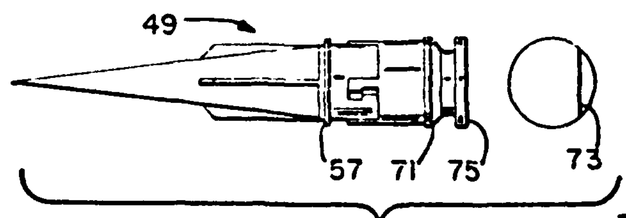

FIG_21C

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LIQUID PROPELLANT WEAPON

BACKGROUND OF THE INVENTION

1. Field of the Invention

The invention relates to a liquid propellant weapon. The invention relates particularly to a small bore liquid propellant weapon of the kind that can be carried and used by an individual infantryman.

2. Description of the Prior Art

Existing weapons for infantrymen use solid propellant cartridges. The existing weapons carry the solid propellant in cases, and the cases form a substantial part of the overall weight of the cartridge. It is characteristic of the solid propellant that the solid propellant develops a high peak temperature.

The trend in small arms development is towards higher projectile velocity. Higher projectile velocity has a number of advantages. Higher velocity yields increased projectile kinetic energy and penetrating power. Smaller projectiles can be used, and the effective range can be increased.

High velocity, conventional, cased ammunition purchases performance at the expense of increased propellant charge and a larger cartridge case.

The high peak temperatures of solid propellants also can cause problems of barrel erosion. This has limited the velocity obtainable with solid propellants in small bore weapons.

Caseless solid propellant systems have been investigated in an attempt to eliminate the weight of the case. The caseless solid propellant systems have not avoided the problem of high propellant peak temperatures which, heating the barrel, limited the projectile velocity that can be obtained.

Liquid propellant weapons have a characteristic low peak temperature. Substantial investigation has been made of the use of liquid propellants for automatic weapons. However, most of the prior liquid propellant weapon work completed to date has involved equipment of a bore-size larger than caliber 0.60. Prior work with large bore liquid propellant weapons has been directed to a projectile loading concept based on a bore-size chamber in which a caseless projectile is loaded into the breech and is subsequently pumped into the forcing cone by the propellant charge which then completely fills the combustion chamber. While facilitating the projectile loading process, this geometry results in two problems. It becomes extremely difficult to retrieve the projectile in the event of a misfire, since no connection is available to the projectile, nor is there a convenient means of effecting an attachment once the projectile is in place.

An equally important consideration is that of performance limitations. In weapons requiring high muzzle velocity and hence large propellant-to-projectile mass ratio the length to diameter ratio of the combustion chamber becomes excessive for acceptable interior ballistics. The bore-size chamber approach, therefore, has been considered to be limited to velocities of approximately 4,000 feet per second or less.

SUMMARY OF THE INVENTION

The small bore liquid propellant weapon of the present invention has a combustion chamber diameter which is much larger than the bore of the barrel of the weapon.

In a preferred form of the invention the weapon includes a reciprocating combustion chamber housing which allows the formation of a combustion chamber without the introduction of ullage in a ballistic system in which the combustion chamber diameter is larger than the bore diameter of the barrel.

The low length to diameter ratio of the combustion chamber results in a short reciprocating stroke. This minimizes receiver length and improves chamber wall cooling. This also permits the use of a stationary lock for the combustion chamber. It provides a convenient means of thermal isolation of the combustion chamber and a convenient means of handling a projectile in a gun employing chambrage. It permits the velocity level to be readily increased by using a longer chamber and stroke. It also permits the length of propellant passages in a receiver mechanism to be limited, and this in turn simplifies the mechanism, eliminates voids and eliminates propellant filled passages which could transmit flame from the combustion chamber to the propellant supply in the magazine.

In the present invention the projectile is carried in a projectile carrier which is separated from the projectile prior to firing. The projectile is a low drag conical projectile. It has the shape of a reentry body with a narrow angle cone and is aerodynamically stabilized.

The carrier contains a percussion igniter which allows the use of existing ignition techniques applicable to any of the current liquid propellant systems.

The carrier can be reengaged with the projectile to remove the projectile in the event of misfire.

The projectile carrier is also a key element in transporting the projectile through the larger than bore diameter chamber (chambrage) which is necessary in a high performance gun.

The weapon of the present invention includes a magazine which has a pumping mechanism integral with the magazine. The pumping mechanism is operated by the action of the reciprocating bolt of the weapon. A propellant supply valve and high pressure seals on the valve are an integral part of the magazine. The incorporation of the high pressure seals as an integral part of the magazine, and the manner in which the magazine and the high pressure valve are associated with the rest of the weapon have several advantages. The high pressure valve element and seals have to operate only for the life of the magazine. The valve element and seals are discarded with the empty magazine. A new high pressure inlet valve element and new high pressure seals are provided each time the magazine is replaced.

Other and further objects of the present invention will be apparent from the following description and claims and are illustrated in the accompanying drawings which, by way of illustration, show preferred embodiments of the present invention and the principles thereof and what are now considered to be the best modes contemplated for applying these principles. Other embodiments of the invention embodying the same or equivalent principles may be used and structural changes may be made as desired by those skilled in the art without departing from the present invention and the purview of the appended claims.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a side elevation view of a small bore liquid propellant weapon constructed in accordance with one embodiment of the present invention;

FIG. 2 is a side elevation view in cross section of a projectile-carrier assembly constructed in accordance with one embodiment of the present invention;

FIG. 3 is an end elevation view taken along the line and in the direction indicated by the arrows 3—3 in FIG. 2;

FIG. 4 is a side elevation view of the carrier alone;

FIG. 5 is a side elevation view of the projectile alone;

FIG. 6 is an end elevation view taken along the line and in the direction indicated by the arrows 6—6 in FIG. 5;

FIG. 7 is a side elevation view (partly broken away to show details of construction) of a magazine constructed in accordance with one embodiment of the present invention;

FIG. 8 is an end elevation view taken along the line and in the direction indicated by the arrows 8—8 in FIG. 7;

FIG. 9 is a fragmentary, enlarged, side elevation, cross-sectional view showing the magazine loaded in the weapon;

FIG. 10 is a top plan view taken generally along the line and in the direction indicated by the arrows 10—10 in FIG. 9;

FIGS. 11-15 are schematic side elevation views of the structure shown in FIG. 9 showing the position assumed by the different elements of the structure during a cycle of automatic firing operation;

FIG. 16 is a graph showing the comparison of temperatures in a barrel for solid propellants and for liquid propellants;

FIG. 17 is a graph showing the drag coefficient for different types of projectiles;

FIG. 18 is a fragmentary side elevation view in cross-section, like FIG. 9, of a weapon constructed in accordance with another embodiment of the present invention. The embodiment shown in FIG. 18 incorporates a reciprocating combustion chamber housing;

FIG. 19 is an end elevation view taken generally along the line and in the direction indicated by the arrows 19—19 in FIG. 18;

FIG. 20 is a plan view showing the cam paths for actuating the bolt of the embodiment shown in FIG. 18;

FIGS. 21 A through D are side elevation views of a carrier incorporating a positive misfire extraction construction;

FIG. 22 is a side elevation of a magazine constructed in accordance with another embodiment of the present invention;

FIG. 23 is a fragmentary sectional view taken generally along the line and in the direction indicated by the arrows 23—23 in FIG. 22; and

FIG. 24 is a detail view of a strap transfer mechanism.

DESCRIPTION OF THE PREFERRED EMBODIMENT

A small bore liquid propellant weapon constructed in accordance with one embodiment of the present invention is indicated generally by the reference numeral 41 in FIG. 1.

The weapon 41 is illustrated as a shoulder weapon. The present invention could also be embodied in other types of weapons, such as hand weapons or vehicle mounted weapons.

The principal components of the weapon 41 are a barrel 43, a receiver assembly 45 and a magazine 47.

The receiver assembly will be described with reference to FIGS. 9 and 10 for one embodiment of the present invention and with reference to FIGS. 18 and 19 with reference to another embodiment of the present invention.

The magazine 47 will be described below with reference to FIGS. 7, 8, 9, 18, 22 and 23.

The magazine 47 supplies liquid propellant and projectiles to the receiver assembly 45 of weapon 41. Each of the projectiles is transported through the magazine and receiver assembly and into the firing chamber by a carrier. The projectile is separated from the carrier prior to firing.

A projectile-carrier assembly constructed in accordance with one embodiment of the present invention is illustrated generally by the reference numeral 49 in FIG. 2. The projectile-carrier assembly 49 includes a projectile 51 and a carrier 53.

The projectile 51 may have a reentry body configuration (as illustrated) with a narrow angle cone. The reentry body shape is aerodynamically stabilized and has a low drag coefficient as shown by the chart of FIG. 17. The projectile can also be a conventional spin stabilized configuration.

The projectile 51 includes in bore stabilizing fins 55, a projectile seal 57, propellant flow grooves 59 and recesses or grooves 61 for attachment to the carrier 53.

The seal 57 also serves to retain the projectile in the barrel after the projectile is loaded.

The carrier 53 has a relatively short axial length so as to contribute little additional length to the overall projectile-carrier assembly. The carrier has a number of forwardly extending fingers or clips 63, and each finger or clip 63 has a radially inwardly extending dimple or projection 65 which seats in a groove 61 of the projectile.

When the carrier projectile assembly is placed in the bore, liquid propellant is pumped through the propellant flow groove 59 and between the back face 67 of the projectile and the inner face 69 of the carrier to pump or force the carrier 53 backwards to the rear end of the firing chamber of the receiver assembly in a manner which will be described in detail below with reference to FIGS. 11-15. The resilient fingers 63 flex to permit the dimple 65 to release from the groove 61 during this separation operation.

In the event of a misfire the carrier 53 can be moved forward and can be reconnected with the projectile 51 to extract the projectile from the firing chamber in a manner also to be described in greater detail below.

The carrier 53 includes a carrier seal 71.

The carrier also includes an alignment flat 73, best shown in FIG. 3. The alignment flat 73 coacts with a corresponding flat on the bolt to align the projectile-carrier assembly in a manner to be described below.

The flat 73 maintains orientation of the carrier relative to the projectile during the cycle, thus insuring that the dimples will properly reengage the projectile in the event it must be removed from the bore in the event of malfunction.

The carrier 53 also includes an extraction lip 75. This extraction lip 75 is engaged by a part on the bolt after the projectile has been fired.

The magazine 47 (as shown in FIGS. 7, 8, 9, 22 and 23) carries both the propellant and the projectile-carrier assemblies. The propellant supply is carried in a flexible tank or reservoir 79 within the magazine

housing. As best shown in FIGS. 22 and 23 the flexible tank 79 may have accordion type pleating and can be operated by a tape drive mechanism 181 actuated by the bolt to lift the bottom of the tank 79 on each cycle of operation to pump propellant into the weapon.

The magazine shown in FIG. 7 includes expansion tanks 81 connected to the main tank 79 by conduits 83.

As best shown in FIG. 9 the propellant supply part of the magazine includes a spring loaded valve element 85 which seats in a valve seat 87 when the magazine is not associated with the weapon. When the magazine is connected to the weapon, downwardly extending tube 89, as shown in FIG. 9, pushes the valve element 85 downwardly to establish fluid communication through a slot 91 in the sidewall of the tube 89.

The projectile-carrier assemblies are fed upwardly through a pair of channels 93 and into a common channel 95 and then into the receiver assembly of the weapon by the same bolt actuated elevator mechanism used to lift the bottom wall of the propellant supply tank or reservoir 79.

A specific description of the lift mechanism for the magazine is set forth below with reference to FIGS. 22–24.

A strippable top 97 retains the projectiles in place until the magazine is loaded into the weapon.

A number of liquid propellants have been found satisfactory for the weapon of the present invention. They include but are not limited to mono propellants such as hydrazine nitrate composed of 35% $N_2H_5NO_3$, 5% H_2O and 60% N_2H_4; Monomethyl Hydrazine Nitrate 90%; Ethyl Propyl Nitrate 60/40; Otto Fuel II.

A metal partition in the magazine serves to positively isolate the primers in the projectile-carrier assembly from the propellant in the tank 79 to preclude inadvertent ignition. A suitable strap transfer mechanism can be associated with the elevator strap 101, as shown in FIG. 24.

The receiver assembly 45, as shown in FIG. 9, has a two-part bolt assembly. The bolt assembly includes an outer bolt 103 and an inner bolt 105.

The outer bolt is reciprocal within a bore 107 in the receiver assembly 45 and barrel 43.

The inner bolt 105 is reciprocable within a bore 109 in the outer bolt.

The tube 89 connecting the propellant supply in the magazine also connects a tube or conduit 111 in the receiver assembly through a propellant control valve 113. The forward end of the tube 111 slides within a bore 114 in the outer bolt in trombone fashion during the reciprocation of the outer bolt 103.

A seal 110 seals between the tube 111 and the bore 113.

The forward end of the conduit 116 connects to the combustion chamber 115 through a spring biased one way ball check valve 117 in the forward face of the outer bolt 103.

A seal 119 is carried at the forward end of the outer bolt to seal against the wall 107 of the combustion chamber 115.

The forward end of the inner bolt 105 includes extractor clip 121 which is resiliently biased by a spring 123. The forward ends of the resilient arms of the clip 121 clip over the extraction lip 75 of the carrier to remove the carrier from the bore 109 after firing.

An off center ejector pin 125 in the inner bolt (See FIG. 15) kicks the carrier out through an ejection slot 127 in the outer bolt and in the receiver assembly 45.

A firing pin 129 is reciprocable within a bore 131 in the inner bolt 105 to ignite the propellant igniter 77 in the carrier.

A bolt lock 133, see FIG. 10, is pivoted about a pivot 135 and is spring biased towards the position illustrated in FIG. 10 by a spring 137 to place the forward face of the bolt lock in locking engagement with the rear face 139 of both the outer bolt 103 and the inner bolt 105. A cam 139 moves forward and engages a corresponding cam surface 141 on the bolt lock 133 to pivot the bolt lock against the force of the spring 137 to release the bolt at the end of the firing cycle.

The operation of the weapon thus far described is illustrated in FIGS. 11–16 which illustrate respectively projectile transfer, projectile ramming, propellant loading, combustion, and the carrier ejection.

The automatic firing cycle is initiated with the bolt in the open position after the firing of a burst. This eliminates cook-off of a round in the hot breech. Propellant isolation is effected by supplying the propellant through the bolt. This allows insertion of a thermal barrier between the barrel and receiver group, effectively isolating the hot barrel from those components in direct contact with liquid propellant.

There is little likelihood of dynamic cook-off of propellant during loading. Static cook-off, however, can be a problem, as it is with caseless solid propellant ammunition.

It is therefore an important feature of the present invention that the propellant supply is isolated from those hot surfaces which might effect ignition of a chambered round or ignition in the propellant supply.

When released by the trigger operated sear, the bolt picks up a carrier and projectile from the clip and inserts the assembly into the bolt bore. The bolt-operated elevator mechanism of the magazine, described above, effects this action by lifting the entire string of projectile-carrier assembly described above.

The flat 73 on the carrier extractor ram aligns the carrier.

The bolt is then driven forward, as illustrated in FIG. 12, by the operating mechanism until the projectile 51 engages the bore opening of the weapon at the forward end of the combustion chamber 115.

The propellant valve 113 is then opened, as illustrated in FIG. 13. This allows propellant supply pressure to 1) seat the projectile, 2) separate the projectile carrier from the projectile within the bolt, and 3) fill the combustion chamber 115 with propellant as the bolt is moved rearward, as illustrated in FIG. 13, to its firing position.

During this phase of operation the propellant flows past the one-way ball check valve 117 and enters the carrier through the opening between the fingers or clips 63 in the carrier wall. The propellant flows through the propellant flow grooves 59 in the projectile 51 and acts on the rear face 67 of the projectile 51 and the forward inner face 69 of the carrier.

When the firing chamber 115 is filled, the bolt is locked in its rear position by the lock 133 (See FIG. 10).

The firing pin 129 is released, and the firing pin strikes the percussion primer 77, igniting the liquid propellant charge in the combustion chamber 115.

After projectile exit, the bolt is opened, the spent projectile carrier is ejected as illustrated in FIG. 15,

and a subsequent cycle is initiated as long as the trigger is depressed.

The weapon may also be operated in a semi-automatic mode if a burst has not been fired recently. In the semi-automatic mode the man firing the gun hand operates an operating handle to fill the firing chamber 115 with propellant and to position the parts in their relative positions as assumed at the end of propellant loading as illustrated in FIG. 13. In this case the weapon is in effect cocked and ready to fire when the trigger is pulled and the firing pin is released to engage the igniter 77 as illustrated in FIG. 14. The weapon can continue to operate in the semi-automatic mode as long as the chamber 115 does not become hot enough to allow static cook-off.

A thermostatic element can be included in the weapon to override semi-automatic operation when the chamber housing is too hot to allow semi-automatic operation from a filled chamber.

As illustrated in FIG. 17 the drag coefficient for the reentry body projectile is quite low, especially in comparison to projectiles having configurations which are presently being used. The small bore liquid propellant gun of the present invention permits the use of this reentry body configuration by providing the requisite high velocity for aerodynamic stabilization. The weapon of the present invention can produce high velocity (as a practical matter) because the liquid propellant combustion does not heat the barrel as much as solid propellant combustion. The cooler burning characteristics of the liquid propellant are graphically illustrated in FIG. 16. This figure shows the envelope of peak bore surface temperatures during eight round bursts of liquid and solid propellant ammunition.

A weapon constructed in accordance with another embodiment of the invention is illustrated in FIGS. 18, 19 and 20.

The weapon shown in FIGS. 18 and 19 embodies two important features.

A reciprocating combustion chamber housing slides over the rear end of the barrel and replaces the conventional bolt mechanism.

The magazine is a completely self-contained magazine which incorporates a propellant pump, a chamber high pressure inlet valve and a clip of projectile-carrier assemblies.

When the reciprocable combustion chamber housing of the embodiment of the weapon shown in FIG. 18 is fully forward, the combustion chamber is completely eliminated. As the housing moves to the rear, the combustion cavity is formed in a manner which eliminates ullage.

This embodiment of the present invention achieves a low length to diameter ratio for the combustion chamber. This minimizes receiver length and improves chamber wall cooling due to the liquid annulus remaining at the time of initiation.

This reciprocating housing construction permits the use of a static lock for the combustion chamber.

Combustion loads are not carried through a receiver but are carried through the static members linking the barrel to the chamber.

It provides convenient means of thermal isolation for the chamber.

It permits ready increase of velocity level by using a longer chamber and stroke.

Propellant passages in the receiver mechanism are eliminated which simplifies the mechanism, eliminates voids and eliminates propellant filled passages which could transmit flame from the combustion chamber to the propellant supply in the magazine.

As illustrated in FIG. 18 a combustion chamber housing 161 slides back and forth on the outer surface 163 of the end of the barrel 43.

The housing 161 is shown in its rearward most position in FIG. 18 ready for firing. The combustion chamber housing 161 and the bolt 105 are held in this position by a static or stationary lock 165. The lock 165 abuts the back face of the housing 161. The lock 165 includes an inner recess 167 hwich engages a radially projecting tang 169 of the bolt. The tank 169 is rotated into locking engagement with the recessed surface 167 of the lock.

A seal 171 at the forward end of the housing 161 seals between the housing 161 and the barrel surface 163.

Liquid propellant is admitted to the combustion chamber 151 through a port 173 in the housing 161.

A valve element 175 controls the admission of liquid propellant through the port 173. The valve element 175 is reciprocable within a bore 177 in the housing 161, and a vent 179 vents the forward end of the bore 177.

As described below, a strap transfer mechanism 181 is operated by movement of the bolt to lift a toothed strap 101 to elevate the bottom wall of the propellant tank 79 and the bottom wall of the clip for the projectiles on each cycle of operation.

FIGS. 22 and 23 illustrate schematically operation of the strap transfer mechanism 181. Two straps 101 are provided, one to raise the projectiles and the other to compress the propellant supply bellows.

The strap transfer drive tang 184 engages a slot in the bolt which causes reciprocation of drive tang 184. During rearward motion of the tang its teeth engage corresponding teeth on plastic strap 101 causing it to be transported to the rear and at the same time rotating take up reel 188. When the bolt moves forward, holding clutch 186 prevents relaxation of the tension on strap 101. Excess tension in the strap is prevented by slipping action between the drive teeth of tang 184 and strap 101 which is controlled by the spring load on holding clutch 186.

FIG. 19 illustrates the manner in which the projectile-carrier assemblies are fed into position in the front of the bolt.

A pair of resilient clips at the upper end of the passage 95 holds the uppermost projectile in position until the forward movement of the bolt pushes the projectile carrier into the combustion chamber.

A tang or cam follower 183 on the bolt engages a groove or cam path 185 to control rotation of the bolt during reciprocating movement as illustrated in FIG. 20.

As noted above, the flow of propellant to the combustion chamber 51 is under the control of a valve element 175. This valve element 175 is a part of a pumping assembly which is indicated generally by the reference numeral 191 and which is an integral part of the magazine 47.

The pumping assembly 191 includes three operating elements. These elements are a reciprocable outer housing 193, a piston 195 and the valve element 175.

The piston 195 slides within a bore 197 within the outer housing 193, and is connected to a piston rod 199 which extends outwardly through a sealed opening in the rearward end of the outer housing 193.

The valve element 175 is connected to a rod 201 which extends through a seal in the piston 195 and which is reciprocable within a bore 203 in the rod 199.

The outer housing 193, the rod 199 and the rod 201 each have an upwardly extending lip which is releasably engaged by an operating element 205, 207 and 209 respectively of the weapon.

The rear face of the valve element 175 has a seal element 211 which engages a forward annular face of the outer housing 193 in sealing relationship in the position illustrated in FIG. 18.

The valve element 175 also includes sealing members 213 and 215. These sealing elements are high pressure seals which prevent any flow out the combustion chamber 151 during combustion.

Propellant is drawn into the chamber formed in the bore 197 in front of the piston 195, during one phase of operation of the weapon, through a conduit 217 in the outer housing 193 and past a spring biased one-way ball check valve 219. The conduit 217 has an extension 217A which compensates for reciprocation of the conduit 217 within the reservoir 79 to prevent an unequal displacement of volume during reciprocation.

As in the embodiment of the invention described with reference to FIGS. 9–15, the embodiment illustrated in FIGS. 18 and 19 can operate in two modes — the automatic mode for firing bursts and semi-automatic mode.

The automatic mode is started with the bolt 105 fully retracted behind the projectile assembly. The reciprocating combustion chamber housing 161 is fully rearward with the rear face 166 in abutment with the lock 165.

At this point the strap 161 has operated to lift the bottom of the magazine to position a projectile-carrier assembly in front of the bolt.

The bolt 105 is then moved forward. This transfers the projectile-carrier assembly forward until the projectile 51 is seated in the barrel and the elastomer seal 57 engages the inside of the barrel to form a liquid seal.

Locking and unlocking of the bolt is controlled by the action of the cam path 185 on the bolt cam follower 183. Forward and backward movement of the cam slide 160 is controlled by the gas piston push rod 162. This camming action rotates the bolt prior to forward or backward movement of the bolt assembly. A manual override 164 is provided to permit hand operation of the bolt in event of misfire.

In a typical firing cycle the gas piston push rod 162 is driven to the rear by combustion gasses as the projectile passes by a gas port near the muzzle. Rearward motion of the push rod 162 and cam slide 160 rotate the bolt cam follower 183 counterclockwise (viewed from the rear) to disengage the bolt tang 169 from the bolt lock inner recess 167 allowing the bolt to move to the rear, extracting and ejecting the spent projectile carrier. At its rearmost position the bolt picks up a new projectile and carrier assembly and during forward motion loads this assembly into the combustion chamber housing. Continued forward motion of the cam slide 160 rotates the bolt clockwise and carries the combustion chamber housing 161 forward until barrel surface 44 is in abutment with housing surface 160 at which time the pumping cycle is initiated as described above.

FIGS. 21A–D show another embodiment of a projectile-carrier assembly incorporating a coacting tang and slot construction for positive extraction in the event of misfire. The propellant-flow ports and grooves are omitted in FIGS. 21A–D for clarity of illustration but are the same as in the embodiment shown in FIGS. 2–5.

As best shown in FIG. 21B, the carrier has a tang 70 the end of a finger 63.

As best shown in FIG. 21D the projectile has a slot 60 with a recess 62.

In normal operation the tang 70 does not engage the recess 62. The spring action of the fingers 63 hold the projectile in place during loading.

If there is a misfire, the normal counterclockwise rotation of the bolt causes the tang 70 to be engaged in the recess 62 when the carrier is reconnected to the unfired projectile.

The tang 70 is never engaged in the recess 62 except in the event of a misfire. The normal loading and locking movement of the bolt is clockwise.

As the bolt is moved forward, the outer housing 193 of the pumping assembly 191 is also moved forward with the valve element 175. This permits propellant to flow through the passage 217 and pass the check valve 219 into a chamber which is formed between the front face of the piston 195 and the rear inner face of the forward part of the valve of the outer housing 193.

The forward movement of the outer housing 193 and the valve element 175 is then discontinued while the forward movement of the valve element 175 is continued. The valve element 175 jogs forward enough to uncover the port 173. Propellant can then flow from the chamber in front of the piston 195 through the bore 231 in the center part of the forward end of the outer housing 193 and through the port 173 and into the combustion chamber 151.

The outer housing 193 is then moved to the rear by the actuating mechanism 205 while the piston 195 is held stationary. This pumps the propellant into the combustion chamber 151. This in turn moves the reciprocating combustion chamber housing 161 to the rear and separates the carrier 53 from the projectile 51.

When the rearward movement of the pump outer housing 193 and the combustion chamber housing 161 has been completed, and the housing 161 is in abutment with the stationary lock 165, actuating element 209 then pulls valve element 175 rearward to the position illustrated in FIG. 18 in which the high pressure seals 213 and 215 seal off any fluid flow through the port 173.

The bolt 105 is moved to the rear with the rearward movement of the housing 161.

At this point the weapon is ready for firing, and firing is accomplished by the hammer striking the firing pin 129 to force the forward end of the firing pin into engagement with the back face of the carrier 53 to ignite the igniter 77.

A conventional gas operated linkage connected to the bolt gives the bolt a kick to the rear when the projectile passes the gas operator.

An off center ejector pin in the bolt, like the pin 125 shown in FIG. 15 tumbles the spent carrier out through an ejection slot.

In the event of a misfire the valve element 175 is moved forward to uncover the port 173, and a manually actuated misfire mechanism pushes the housing

161 forward to pump out the propellant from the combustion chamber 151.

The bolt 105 is rotated with respect to the carrier 58 to engage the extraction clips of the bolt in the slot of the carrier to produce a positive grip between the bolt and the carrier. The bolt is then pulled back to extract the carrier and the projectile 51, and the entire reengaged carrier and projectile assembly is ejected through the ejection slot at the end of rearward movement of the bolt.

In the semi-automatic mode the parts are manually actuated for the first shot to the relative positions illustrated in FIG. 18 so that the weapon is ready to fire when the trigger is pulled.

As described above, with reference to the first embodiment of this invention, a thermostatic element can be provided to override the semi-automatic operating mechanism when the chamber housing is too hot to allow semi-automatic operation from a filled chamber.

To remove the magazine 47 from the weapon illustrated in FIG. 18, a clip release is actuated to move the outer housing 193, the piston 195 and the valve element 175 to the rear and to release the magazine housing from the receiver 45.

It is an important feature of the embodiment of the present invention shown in FIG. 18 that propellant passages in the receiver mechanism are eliminated. The only free volume is the connection from the combustion chamber 151 to the bore 177 through the relatively small port 173.

The high pressure seals 213 and 215 are replaced each time a new magazine is used.

The flat seal 211 provides positive propellant isolation, and there is always an atmospheric vent after the high pressure seal 215 and before getting to the propellant in the reservoir 79.

While we have illustrated and described the preferred embodiments of our invention, it is to be understood that these are capable of variation and modification, and we therefore do not wish to be limited to the precise details set forth, but desire to avail ourselves of such changes and alterations as fall within the purview of the following claims.

We claim:

1. A method of loading liquid propellant into a firing chamber of a liquid propellant gun to avoid ullage problems comprising placing the forward face of a firing chamber in line contact with the rear face of the firing chamber, loading a projectile carrier assembly in firing position in the bore of the gun while the front and rear faces of the firing chamber are maintained in line contact, then pumping liquid propellant into the firing chamber to displace the rear face of the firing chamber axially with respect to the front face of the firing chamber, separating the carrier from the projectile as liquid propellant is pumped into the firing chamber, retaining the projectile in the forward face of the firing chamber and retaining the carrier in the rear face of the firing chamber as these two faces are axially separated, and then igniting the liquid propellant in the firing chamber to fire the projectile out the barrel of the gun.

2. A method as defined in claim 1 including pumping the liquid propellant out of the firing chamber in the event of a misfire, moving the rear face of the combustion chamber into line contact with the front face of the combustion chamber as the liquid propellant is pumped out of the firing chamber, reconnecting the carrier to the projectile as the faces of the combustion chamber are reengaged in line contact, and then extracting the projectile-carrier assembly from the gun.

3. A method as defined in claim 1 including locating the mechanism for pumping the liquid propellant into the firing chamber in structure associated with the rear face of the firing chamber and maintaining the mechanism for pumping the liquid propellant spaced from the firing chamber housing and from the barrel of the gun after the firing chamber housing and the barrel have been heated to high temperatures by the firing of a burst to thereby provide thermal isolation of the propellant from the hot barrel and the housing.

4. A method as defined in claim 1 wherein the rear face of the combustion chamber is part of a reciprocating combustion chamber housing.

5. A method as defined in claim 1 wherein the rear face of the combustion chamber is a part of the bolt assembly.

6. A liquid propellant gun of the kind in which a projectile is loaded in the gun and liquid propellant is pumped into the combustion chamber behind the projectile and is ignited to fire the projectile from the gun,
- said gun comprising a combustion chamber having a front face and a rear face,
- said front face having an opening for the projectile,
- said rear face being shaped complementary to the front face to engage the front face in line contact across the full surface of the front face except for the area of said opening,
- moving means for moving one face relative to the other face into said line contact with the other face and for moving the one face away from the other face and into firing position,
- projectile loading means coordinated with said moving means for loading a projectile in the opening in the front face while the rear face is engaged in said line contact with the front face across said full surface of the front face,
- pumping means for pumping a liquid propellant into the combustion chamber,
- and propellant control valve means effective to admit the pumped liquid propellant into the combustion chamber at the start of movement of the one face away from the other face and to continue to admit said liquid propellant continuously and in coordination with the movement of the other face by said moving means to said firing position to thereby fill the entire chamber volume with liquid propellant simultaneously with the formation of the chamber and prevent ullage in the combustion chamber.

7. A gun as defined in claim 6 wherein the projectile has an elastomer seal and projectile holder extending circumferentially around the projectile and engageable in fluid sealing and projectile retaining relationship with the opening in the front face of the combustion chamber.

8. A gun as defined in claim 6 wherein the diameter of the combustion chamber is considerably larger than the diameter of the projectile to provide large propellant-to-projectile mass ratios for high muzzle velocities and small combustion chamber length-to-diameter ratios for acceptable interior ballistics.

9. A gun as defined in claim 6 including a magazine containing a clip of projectile-carrier assemblies and a tank of liquid propellant, and wherein the pumping

means include a movable piston and high pressure seals in the magazine structure.

10. A liquid propellant gun of the kind in which a projectile is loaded in the gun and liquid propellant is pumped into the combustion chamber behind the projectile and is ignited to fire the projectile from the gun,

said gun comprising, a combustion chamber having a forward face and a rear face,

said front face having an opening for the projectile,

moving means for moving the rear face forward into line contact with the front face and for moving the rear face backward away from the front face and into firing position,

projectile loading means for loading a projectile in the opening in the front face while the rear face is engaged in line contact with the front face,

pumping means for pumping a liquid propellant into the combustion chamber as the combustion chamber is formed by rearward movement of the rear face whereby ullage in the combustion chamber is avoided, and wherein the projectile loading means include a projectile-carrier assembly having a carrier detachably connected to the projectile for transporting the projectile and wherein the rear face of the combustion chamber has an opening and the carrier is engaged in fluid sealing contact in said rear face opening and is disconnected from the projectile as liquid propellant is pumped into the combustion chamber during rearward movement of the rear face.

11. A gun as defined in claim 10 wherein the carrier and projectile have coacting ports and grooves in the sides of the carrier and projectile for permitting liquid propellant to enter between the back face of the projectile and a forward inner face of the carrier to separate the carrier from projectile.

12. A gun as defined in claim 10 wherein the carrier has a percussive igniter for igniting the liquid propellant.

13. A gun as defined in claim 10 wherein the carrier has a rear carrier rim and a flat formed on the carrier rim for orienting the projectile and carrier assembly with respect to other operating mechanism of the gun.

14. A gun as defined in claim 13 wherein the projectile and carrier have coacting positive locking means which can be engaged to extract the projectile-carrier assembly in the event of a misfire and wherein the flat on the carrier rim permits rotation of the carrier relative to the projectile to actuate the positive locking means.

15. A liquid propellant gun of the kind in which a projectile is loaded in the gun and liquid propellant is pumped into the combustion chamber behind the projectile and is ignited to fire the projectile from the gun,

said gun comprising a combustion chamber having a front face and a rear face,

said front face having an opening for the projectile,

said rear face being shaped complementary to the front face to engage the front face in line contact across the full surface of the front face except for the area of said opening,

moving means for moving one face relative to the other face into said line contact with the other face and for moving the one face away from the other face and into firing position,

projectile loading means for loading a projectile in the opening in the front face while the rear face is engaged in said line contact with the front face, and

pumping means for pumping a liquid propellant into the combustion chamber as the combustion chamber is formed by movement of the faces apart from each other to fill the entire chamber volume with liquid propellant simultaneously with the formation of the chamber whereby ullage in the combustion chamber is avoided and wherein the front face of the combustion chamber is formed on the end of the barrel of the gun, said gun includes a reciprocating combustion chamber housing, the housing includes a forwardly extending portion having one inside surface slidable on and sealingly engaged with the outside surface of the barrel, and another inside surface of the housing forms said rear face of the combustion chamber.

16. A liquid propellant gun of the kind in which a projectile is loaded in the gun and liquid propellant is pumped into the combustion chamber behind the projectile and is ignited to fire the projectile from the gun,

said gun comprising a combustion chamber having a front face and a rear face,

said front face having an opening for the projectile,

said rear face being shaped complementary to the front face to engage the front face in line contact across the full surface of the front face except for the area of said opening,

moving means for moving one face relative to the other face into said line contact with the other face and for moving the one face away from the other face and into firing position,

projectile loading means for loading a projectile in the opening in the front face while the rear face is engaged in said line contact with the front face, and

pumping means for pumping a liquid propellant into the combustion chamber as the combustion chamber is formed by movement of the faces apart from each other to fill the entire chamber volume with liquid propellant simultaneously with the formation of the chamber whereby ullage in the combustion chamber is avoided and including a bolt assembly and wherein the rear face is a part of the bolt assembly and said bolt assembly includes a passageway extending through said rear face and interconnecting the pumping means and the chamber.

17. A liquid propellant gun of the kind in which a projectile is loaded in the gun and liquid propellant is pumped into the combustion chamber behind the projectile and is ignited to fire the projectile from the gun,

said gun comprising, a combustion chamber having a forward face and a rear face,

said front face having an opening for the projectile,

moving means for moving the rear face forward into line contact with the front face and for moving the rear face backward away from the front face and into firing position,

projectile loading means for loading a projectile in the opening in the front face while the rear face is engaged in line contact with the front face,

pumping means for pumping a liquid propellant into the combustion chamber as the combustion chamber is formed by rearward movement of the rear face whereby ullage in the combustion chamber is avoided,

a magazine containing a clip of projectile-carrier assemblies, a tank of liquid propellant, and the pumping means,

a rearwardly extending part of the barrel assembly which includes the front face of the combustion chamber, a reciprocating combustion chamber housing which includes the rear face of the combustion chamber, said housing having a forwardly extending part which has an inner surface slidable on and sealingly engaged with an outer surface of the rearwardly extending part of the barrel, port means in the housing, and a valve element of the pumping means of the magazine associated with the port means of the housing to control the flow of liquid propellant from the magazine to the combustion chamber through the port means of the housing.

18. A gun as defined in claim 17 wherein the valve element has high pressure seals on the valve element for preventing loss of fluid pressure out of the combustion chamber during firing whereby the high pressure seals are replaced each time a new magazine is connected to the gun.

19. A liquid propellant gun constructed to avoid ullage problems in the loading of liquid propellant in the firing chamber, said gun comprising, actuator means for placing the forward face of a firing chamber in line contact with the rear face of the firing chamber, loading means for loading a projectile carrier assembly in firing position in the bore of the gun while the front and rear faces of the firing chamber are maintained in line contact, pumping means for pumping liquid propellant into the firing chamber to displace one face of the firing chamber axially with respect to the other face of the firing chamber, separating means for separating the carrier from the projectile as liquid propellant is pumped into the firing chamber, retaining means for retaining the projectile in the forward face of the firing chamber and for retaining the carrier in the rear face of the firing chamber as these two faces are axially separated, and igniter means for igniting the liquid propellant in the firing chamber to fire the projectile out the barrel of the gun.

* * * * *

United States Patent [19]

Elmore et al.

[11] 3,916,792

[45] Nov. 4, 1975

[54] LIQUID PROPELLANT WEAPON

[75] Inventors: Lester C. Elmore, Portola Valley; Thomas M. Broxholm, Palo Alto, both of Calif.

[73] Assignee: Pulsepower Systems, Incorporated, San Carlos, Calif.

[22] Filed: Oct. 23, 1973

[21] Appl. No.: 408,571

Related U.S. Application Data

[62] Division of Ser. No. 179,759, Sept. 13, 1971, Pat. No. 3,803,975.

[52] U.S. Cl. .... 102/38; 102/43 R; 102/92.1

[51] Int. Cl. F42b 5/02

[58] Field of Search 102/38, 40, 88, 93, 92.4, 102/92.6, 92.7, 45, 43; 89/7

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Primary Examiner—Samuel Feinberg
Assistant Examiner—H. J. Tudor
Attorney, Agent, or Firm—Owen, Wickersham & Erickson

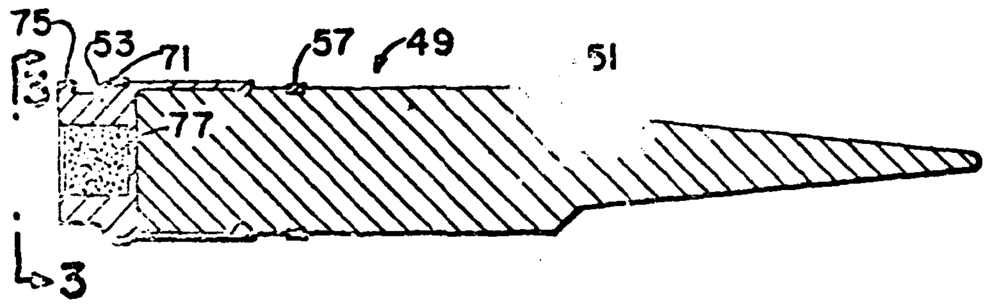
[57] ABSTRACT

A small bore liquid propellant weapon fires projectiles transported to the firing chamber in a projectile carrier. The projectile carrier is separated from the projectile just prior to firing the projectile. The projectile carrier can be reconnected with the projectile to extract the projectile from the weapon in the event of a misfire.

The small bore liquid propellant weapon has a reciprocating combustion chamber housing. The reciprocating combustion chamber housing forms a large diameter combustion chamber without ullage and eliminates a lock.

The small bore liquid propellant weapon includes an integral magazine which has its own pump for the liquid propellant. The magazine also has a valve element with high pressure seals that operate only for the life of the magazine and that are discarded with the empty magazine.

8 Claims, 27 Drawing Figures



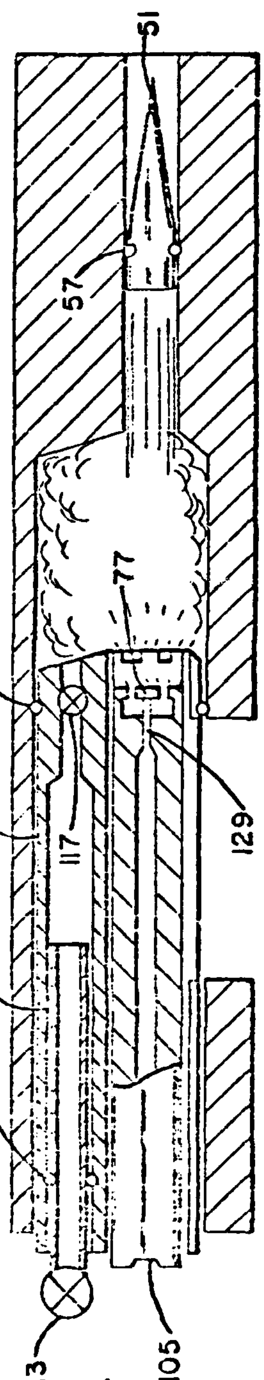


FIG_14

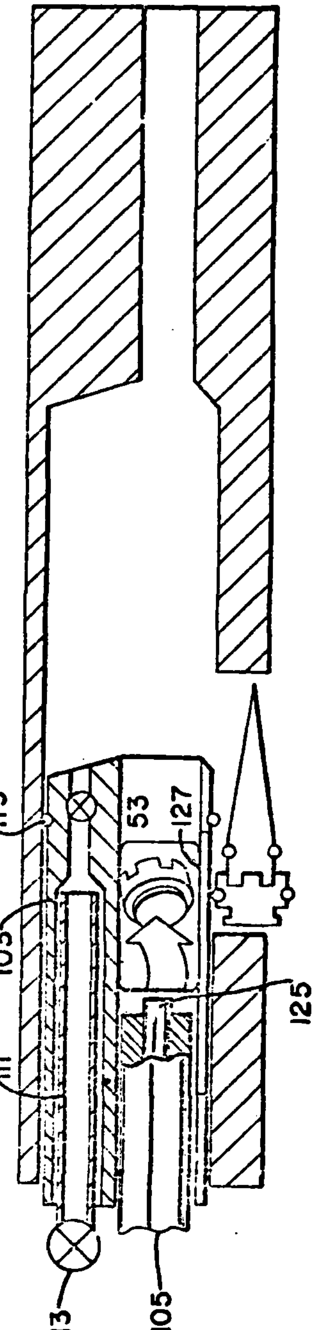


FIG_15

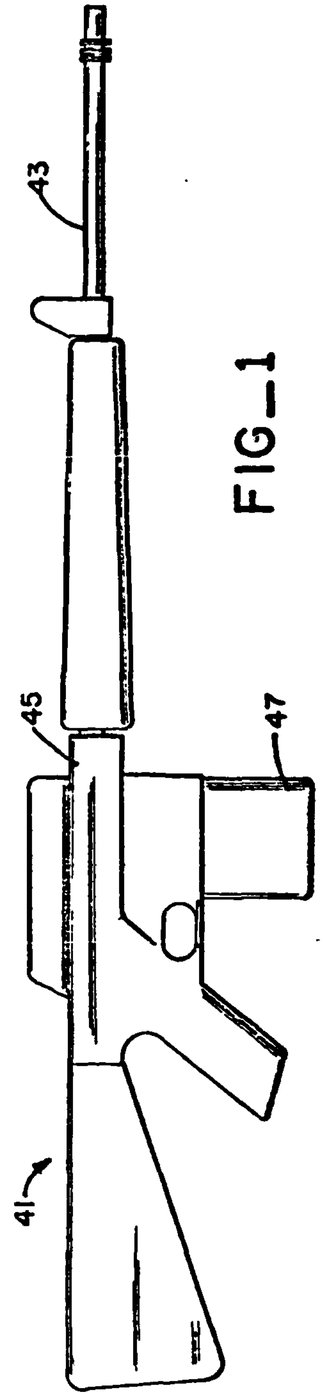


FIG_1

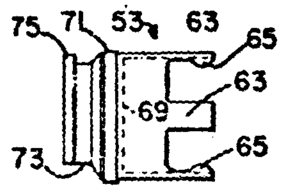


FIG_4

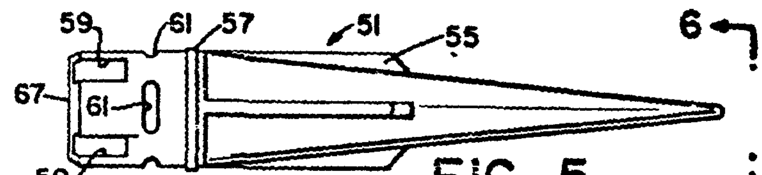


FIG_5

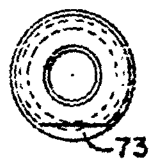


FIG_3

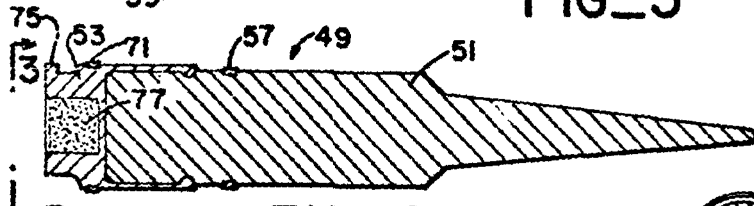


FIG_2

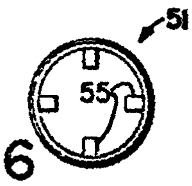


FIG_6

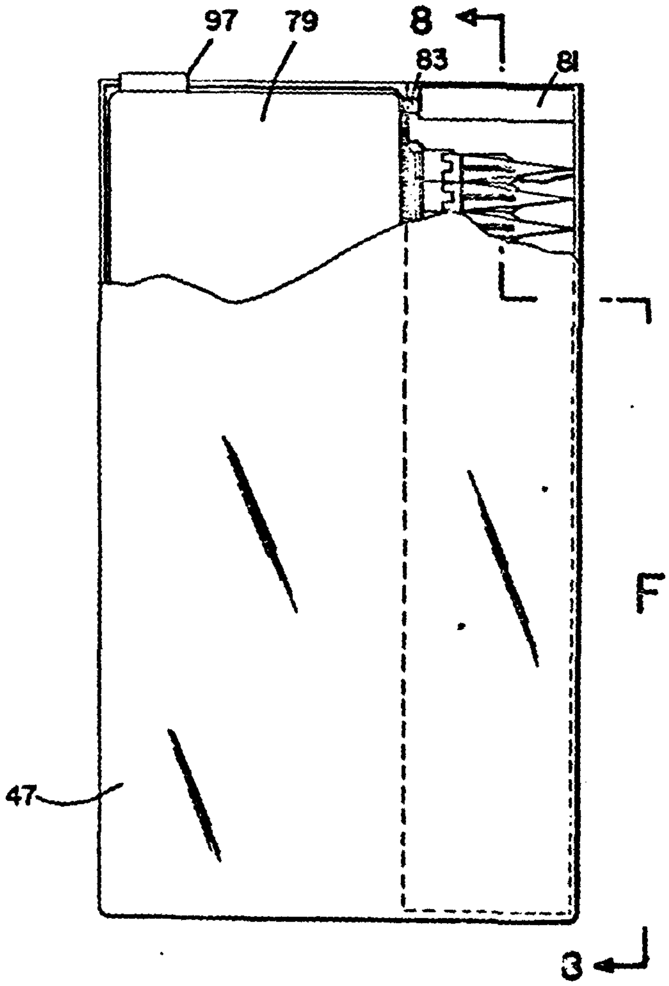


FIG_7

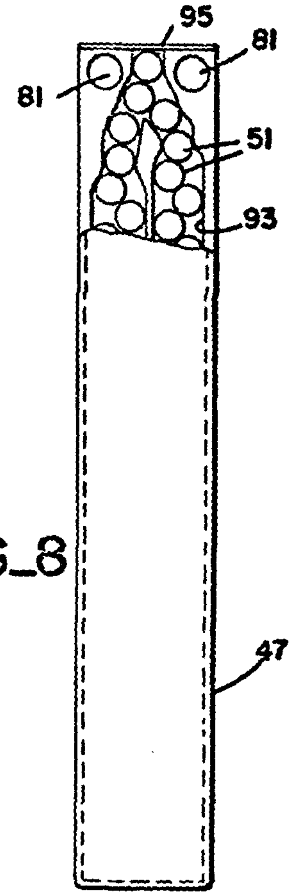


FIG_8

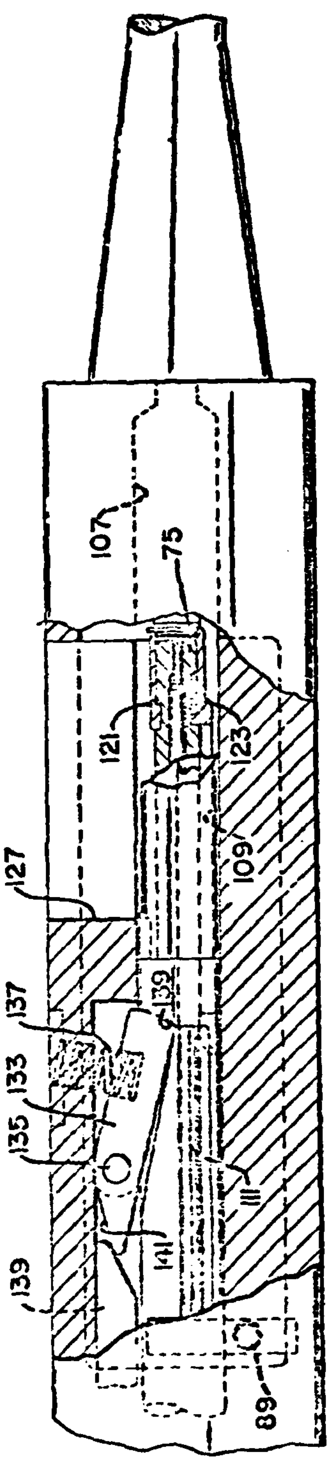
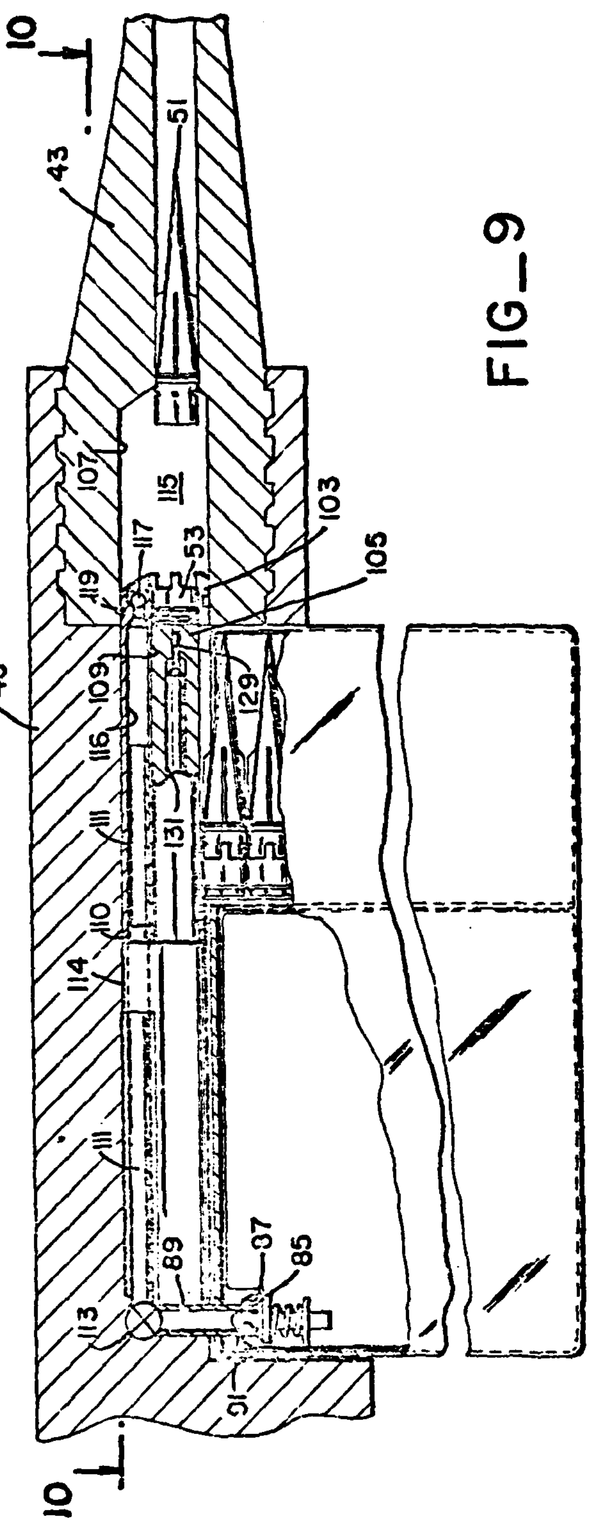

107
75
121
123
109
127
137
139
133
135
111
141
139
89

FIG_10


10
43
51
107
115
117
119
53
103
105
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109
129
116
111
131
110
114
111
89
87
85
113
91
10

FIG_9

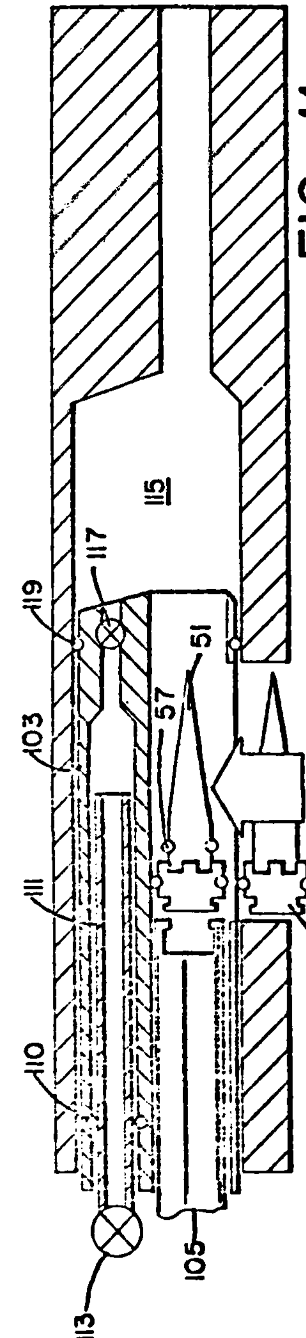

FIG_11

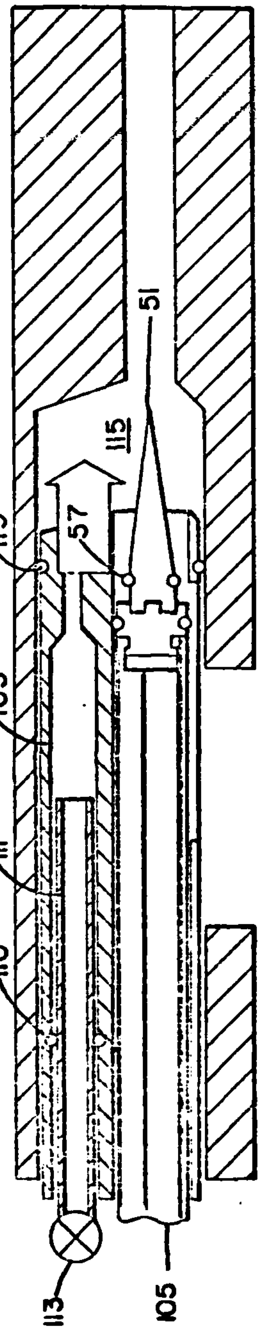

FIG_12

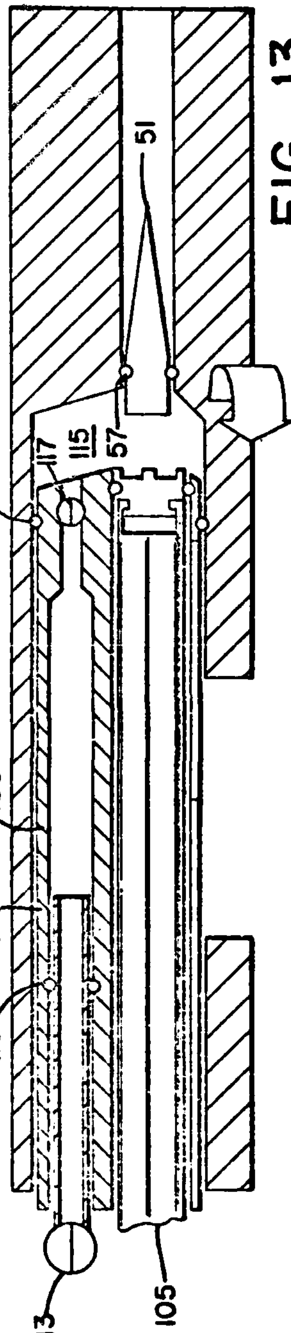

FIG_13

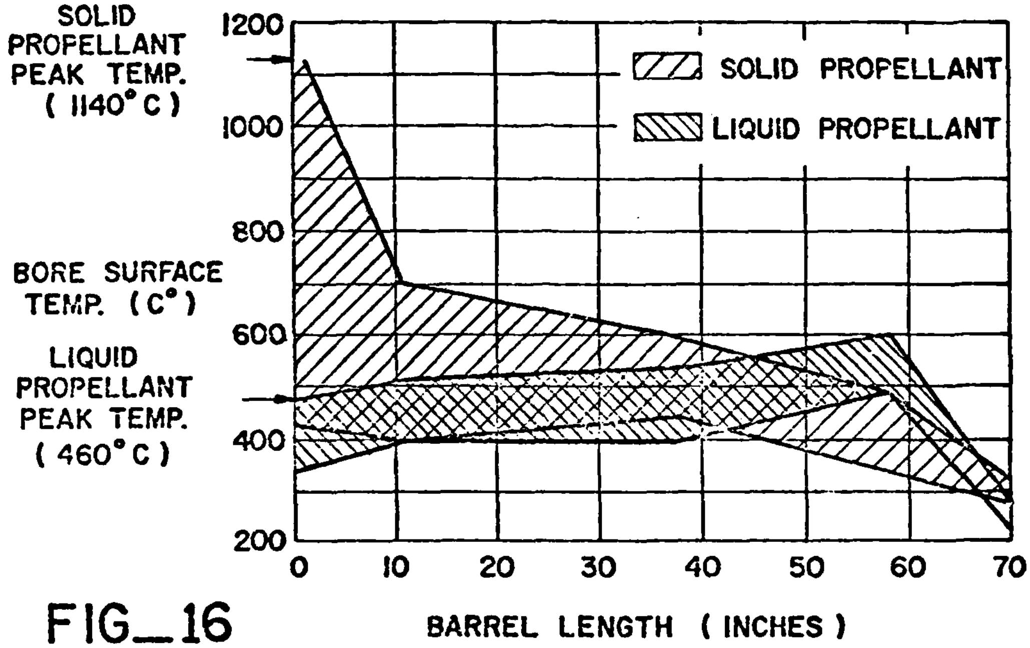
SOLID PROPELLANT PEAK TEMP. (1140° C)
BORE SURFACE TEMP. (C°)
LIQUID PROPELLANT PEAK TEMP. (460° C)
SOLID PROPELLANT
LIQUID PROPELLANT
1200
1000
800
600
400
200
0
10
20
30
40
50
60
70
BARREL LENGTH (INCHES)

FIG_16

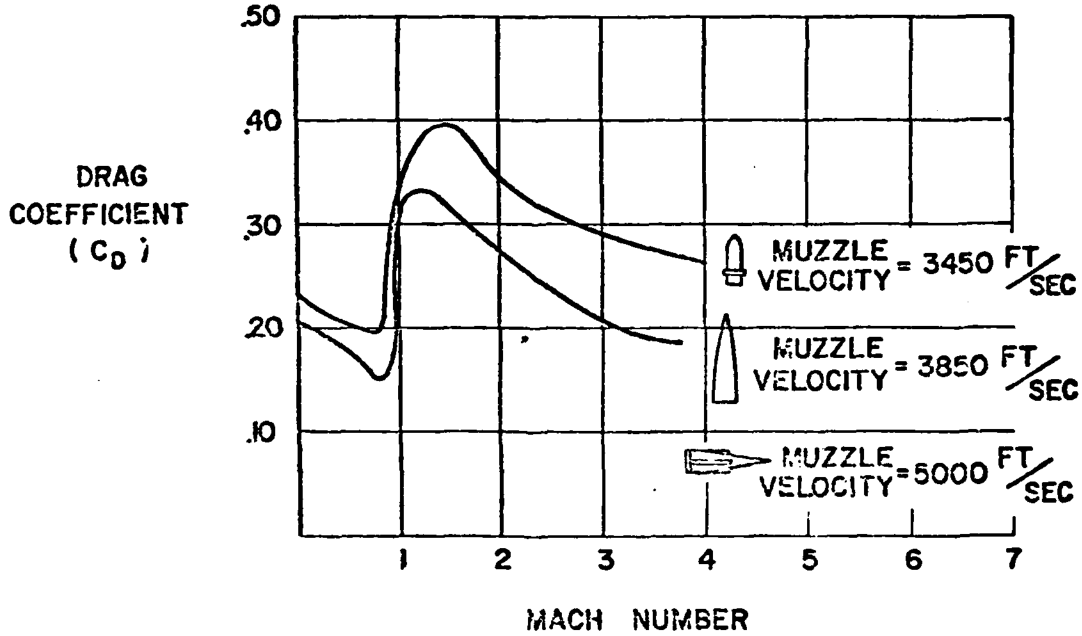
DRAG COEFFICIENT (C_D)
.50
.40
.30
.20
.10
1
2
3
4
5
6
7
MACH NUMBER
MUZZLE VELOCITY = 3450 FT/SEC
MUZZLE VELOCITY = 3850 FT/SEC
MUZZLE VELOCITY = 5000 FT/SEC

FIG_17

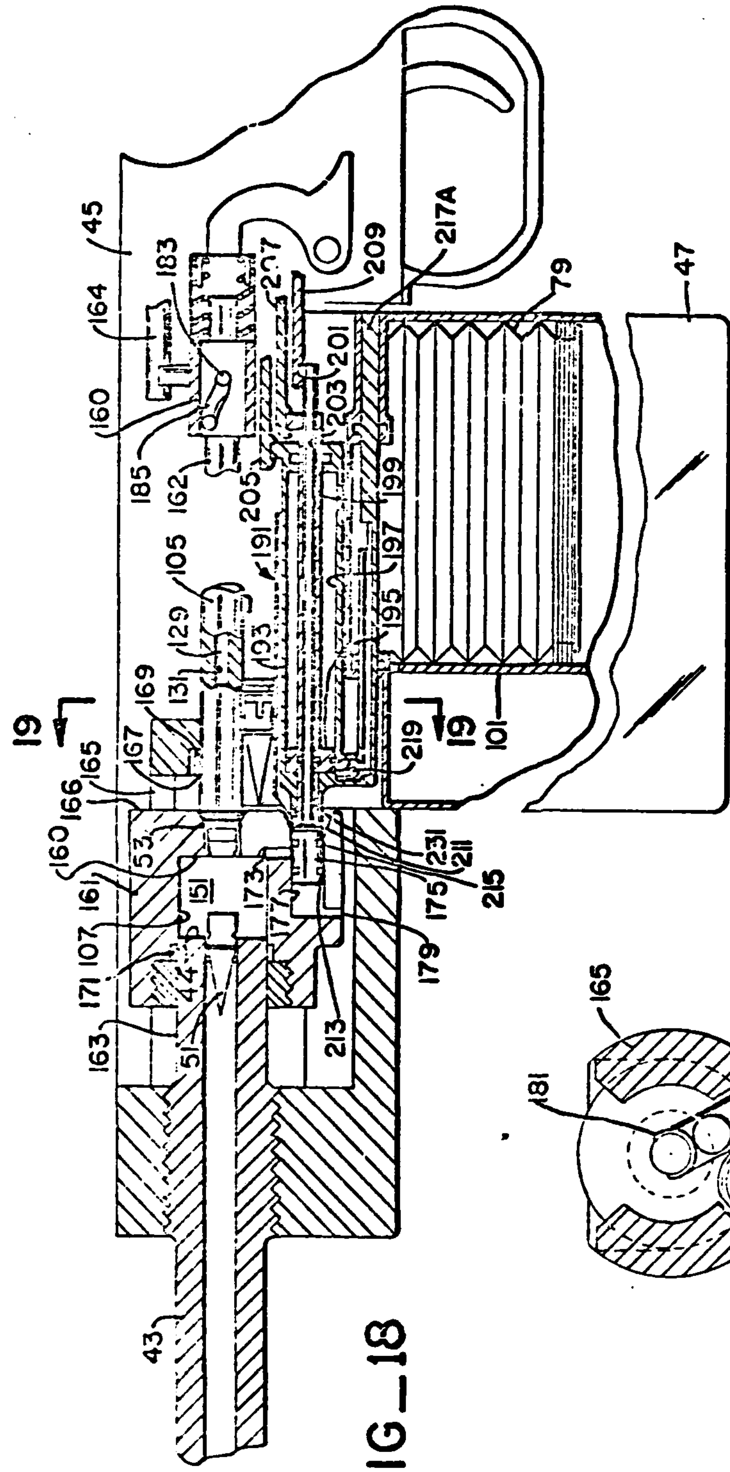

FIG_18

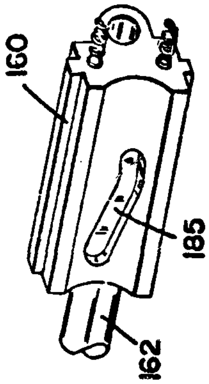

FIG_20

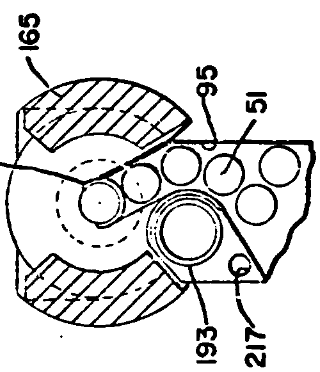

FIG_19

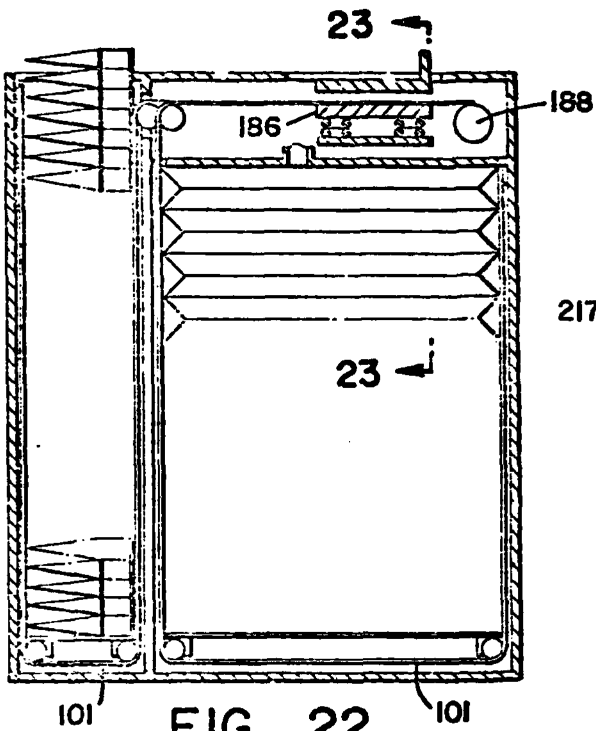

FIG_22

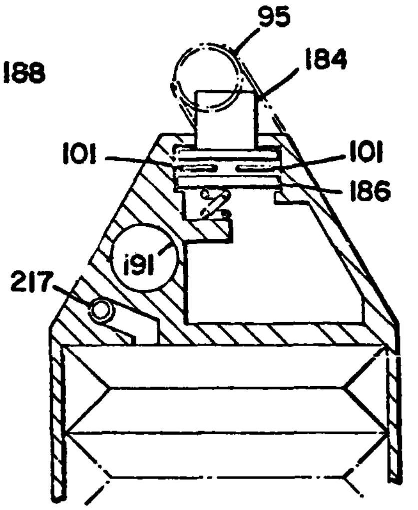

FIG_23

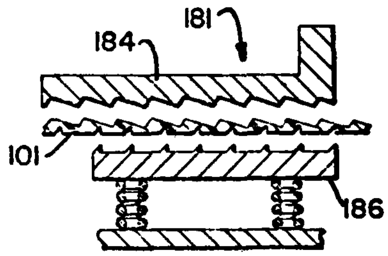

FIG_24

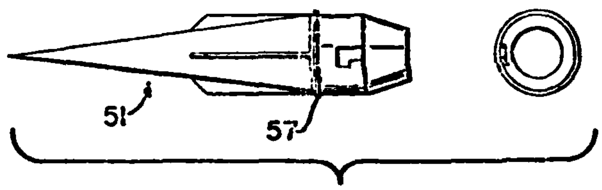

FIG_21A

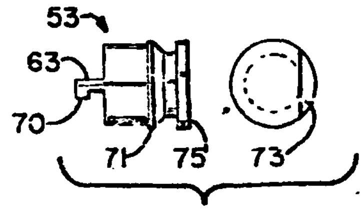

FIG_21B

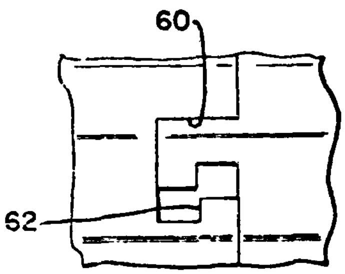

FIG_21D

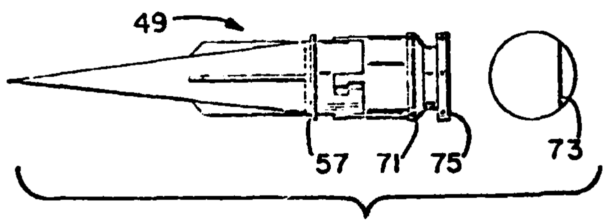

FIG_21C

LIQUID PROPELLANT WEAPON

Some of the inventions herein described were made (first reduced to practice) in the course of or under a contract with ARPA.

BACKGROUND OF THE INVENTION

This application is a division of parent application Ser. No. 179,759 filed Sept. 13, 1971 and entitled "Liquid Propellant Weapon" and claims the benefit of the filing date of the parent application. Parent application Ser. No. 179,759 was issued as U.S. Pat. No. 3,803,975 on April 16, 1974.

BACKGROUND OF THE INVENTION

1. Field of the Invention

The invention relates to a liquid propellant weapon. This invention relates particularly to a small bore liquid propellant weapon of the kind that can be carried and used by an individual infantryman.

2. Description of the Prior Art

Existing weapons for infantrymen use solid propellant cartridges. The existing weapons carry the solid propellant in cases, and the cases form a substantial part of the overall weight of the cartridge. It is characteristic of the solid propellant that the solid propellant develops a high peak temperature.

The trend in small arms development is towards higher projectile velocity. Higher projectile velocity has a number of advantages. Higher velocity yields increased projectile kinetic energy and penetrating power. Smaller projectiles can be used, and the effective range can be increased.

High velocity conventional, cased ammunition purchases performance at the expense of increased propellant charge and a larger cartridge case.

The high peak temperatures of solid propellants also can cause problems of barrel erosion. This has limited the velocity obtainable with solid propellants in small bore weapons.

Caseless solid propellant systems have been investigated in an attempt to eliminate the weight of the case. The caseless solid propellant systems have not avoided the problem of high propellant peak temperatures which, heating the barrel, limit the projectile velocity that can be obtained.

Liquid propellant weapons have a characteristic low peak temperature. Substantial investigation has been made of the use of liquid propellants for automatic weapons. However, most of the prior liquid propellant weapon work completed to date has involved equipment of a bore-size larger than caliber .60. Prior work with large bore liquid propellant weapons has been directed to a projectile loading concept based on a bore-size chamber in which a caseless projectile is loaded into the breech and is subsequently pumped into the forcing cone by the propellant charge which then completely fills the combustion chamber. While facilitating the projectile loading process, this geometry results in two problems. It becomes extremely difficult to retrieve the projectile in the event of a misfire, since no connection is available to the projectile, nor is there a convenient means of effecting an attachment once the projectile is in place.

An equally important consideration is that of performance limitations. In weapons requiring high muzzle velocity and hence large propellant-to-projectile mass ratios the length to diameter ratio of the combustion chamber becomes excessive for acceptable interior ballistics. The bore-size chamber approach, therefore, has been considered to be limited to velocities of approximately 4,000 feet per second or less.

SUMMARY OF THE INVENTION

The small bore liquid propellant weapon of the present invention has a combustion chamber diameter which is much larger than the bore of the barrel of the weapon.

In a preferred form of the invention the weapon includes a reciprocating combustion chamber housing which allows the formation of a combustion chamber without the introduction of ullage in a ballistic system in which the combustion chamber diameter is larger than the bore diameter of the barrel.

The low length to diameter ratio of the combustion chamber results in a short reciprocating stroke. This minimizes receiver length and improves chamber wall cooling. This also permits the use of a stationary lock for the combustion chamber. It provides a convenient means of thermal isolation of the combustion chamber and a convenient means of handling a projectile in a gun employing chambrage. It permits the velocity level to be readily increased by using a longer chamber and stroke. It also permits the length of propellant passages in a receiver mechanism to be limited, and this in turn simplifies the mechanism, eliminates voids and eliminates propellant filled passages which could transmit flame from the combustion chamber to the propellant supply in the magazine.

In the present invention the projectile is carried in a projectile carrier which is separated from the projectile prior to firing. The projectile may be a low drag conical projectile. It has the shape of a reentry body with a narrow angle cone and is aerodynamically stabilized.

The carrier contains a percussion igniter which allows the use of existing ignition techniques applicable to any of the current liquid propellant systems.

The carrier can be reengaged with the projectile to remove the projectile in the event of misfire.

The projectile carrier is also a key element in transporting the projectile through the larger than bore diameter chamber (chambrage) which is necessary in a high performance gun.

The weapon of the present invention includes a magazine which has a pumping mechanism integral with the magazine. The pumping mechanism is operated by the action of the reciprocating bolt of the weapon. An omitted propellant supply valve and high pressure seals on the valve are an integral part of the magazine. The incorporation of the high pressure seals as an integral part of the magazine, and the manner in which the magazine and the high pressure valve are associated with the rest of the weapon have several advantages. The high pressure valve element and seals have to operate only for the life of the magazine. The valve element and seals are discarded with the empty magazine. A new high pressure inlet valve element and new high pressure seals are provided each time the magazine is replaced.

Other and further objects of the present invention will be apparent from the following description and claims and are illustrated in the accompanying drawings which, by way of illustration, show preferred embodiments of the present invention and the principles thereof and what are now considered to be the best modes contemplated for applying these principles. Other embodiments of the invention embodying the

same or equivalent principles may be used and structural changes may be made as desired by those skilled in the art without departing from the present invention and the purview of the appended claims.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a side elevation view of a small bore liquid propellant weapon constructed in accordance with one embodiment of the present invention;

FIG. 2 is a side elevation view in cross section of a projectile-carrier assembly constructed in accordance with one embodiment of the present invention;

FIG. 3 is an end elevation view taken along the line and in the direction indicated by the arrows 3—3 in FIG. 2;

FIG. 4 is a side elevation view of the carrier alone;

FIG. 5 is a side elevation view of the projectile alone;

FIG. 6 is an end elevation view taken along the line and in the direction indicated by the arrows 6—6 in FIG. 5;

FIG. 7 is a side elevation view (partly broken away to show details of construction) of a magazine constructed in accordance with one embodiment of the present invention;

FIG. 8 is an end elevation view taken along the line and in the direction indicated by the arrows 8—8 in FIG. 7;

FIG. 9 is a fragmentary, enlarged, side elevation, cross-sectional view showing the magazine loaded in the weapon;

FIG. 10 is a top plan view taken generally along the line and in the direction indicated by the arrows 10—10 in FIG. 9;

FIGS. 11–15 are schematic side elevation views of the structure shown in FIG. 9 showing the position assumed by the different elements of the structure during a cycle of automatic firing operation;

FIG. 16 is a graph showing the comparison of temperatures in a barrel for solid propellants and for liquid propellants;

FIG. 17 is a graph showing the drag coefficient for different types of projectiles;

FIG. 18 is a fragmentary side elevation view of cross-section, like FIG. 9, of a weapon constructed in accordance with another embodiment of the present invention. The embodiment shown in FIG. 18 incorporates a reciprocating combustion chamber housing;

FIG. 19 is an end elevation view taken generally along the line and in the direction indicated by the arrows 19—19 in FIG. 18;

FIG. 20 is a plan view showing the cam paths for actuating the bolt of the embodiment shown in FIG. 18;

FIGS. 21 A through D are side elevation views of a carrier incorporating a positive misfire extraction construction;

FIG. 22 is a side elevation of a magazine constructed in accordance with another embodiment of the present invention;

FIG. 23 is a fragmentary sectional view taken generally along the line and in the direction indicated by the arrows 23—23 in FIG. 22; and

FIG. 24 is a detail view of a strap transfer mechanism.

DESCRIPTION OF THE PREFERRED EMBODIMENT

A small bore liquid propellant weapon constructed in accordance with one embodiment of the present invention is indicated generally by the reference numeral 41 in FIG. 1.

The weapon 41 is illustrated as a shoulder weapon. The present invention could also be embodied in other types of weapons, such as hand weapons or vehicle mounted weapons.

The principal components of the weapon 41 are a barrel 43, a receiver assembly 45 and a magazine 47.

The receiver assembly will be described with reference to FIGS. 9 and 10 for one embodiment of the present invention and with reference to FIGS. 18 and 19 with reference to another embodiment of the present invention.

The magazine 47 will be described below with reference to FIGS. 7, 8, 9, 18, 22 and 23.

The magazine 47 supplies liquid propellant and projectiles to the receiver assembly 45 of weapon 41. Each of the projectiles is transported through the magazine and receiver assembly and into the firing chamber by a carrier. The projectile is separated from the carrier prior to firing.

A projectile-carrier assembly constructed in accordance with one embodiment of the present invention is illustrated generally by the reference numeral 49 in FIG. 2. The projectile-carrier assembly 49 includes a projectile 51 and a carrier 53.

The projectile 51 may have a reentry body configuration (as illustrated) with a narrow angle cone. The reentry body shape is aerodynamically stabilized and has a low drag coefficient as shown by the chart of FIG. 17. The projectile can also be a conventional spin stabilized configuration.

The projectile 51 includes a bore stabilizing fins 55, a projectile seal 57 which may be an elastomer seal, propellant flow grooves 59 and recesses or grooves 61 for attachment to the carrier 53.

The seal 57 also serves to retain the projectile in the barrel after the projectile is loaded.

The carrier 53 has a relatively short axial length so as to contribute little additional length to the overall projectile-carrier assembly. The carrier has a number of forwardly extending fingers or clips 63, and each finger or clip 63 has a radially inwardly extending dimple or projection 65 which seats in a groove 61 of the projectile.

When the carrier projectile assembly is placed in the bore, liquid propellant is pumped through the propellant flow groove 59 and between the back face 67 of the projectile and the inner face 69 of the carrier to pump or force the carrier 53 backwards to the rear end of the firing chamber of the receiver assembly in a manner which will be described in detail below with reference to FIGS. 11–15. The resilient fingers 63 flex to permit the dimple 65 to release from the groove 61 during this separation operation.

In the event of a misfire the carrier 53 can be moved forward and can be reconnected with the projectile 51 to extract the projectile from the firing chamber in a manner also to be described in greater detail below.

The carrier 53 includes a carrier seal 71 which also may be an elastomer seal.

The carrier also includes an alignment flat 73, best shown in FIG. 3. The alignment flat 73 coacts with a corresponding flat on the bolt to align the projectile-carrier assembly in a manner to be described below.

The flat 73 maintains orientation of the carrier relative to the projectile during the cycle, thus incuring that the dimples will properly reengage the projectile in the

event it must be removed from the bore in the event of malfunction.

The carrier 53 also includes an extraction lip 75. This extraction lip 75 is engaged by a part on the bolt after the projectile has been fired.

The magazine 47 (as shown in FIGS. 7, 8, 9, 22 and 23) carries both the propellant and the projectile-carrier assemblies. The propellant supply is carried in a flexible tank or reservoir 79 within the magazine housing. As best shown in FIGS. 22 and 23 the flexible tank 79 may have accordion type pleating and can be operated by a tape drive mechanism 181 actuated by the bolt to lift the bottom of the tank 79 on each cycle of operation to pump propellant into the weapon.

The magazine shown in FIG. 7 includes expansion tanks 81 connected to the main tank 79 by conduits 83.

As best shown in FIG. 9 the propellant supply part of the magazine includes a spring loaded valve element 85 which seats in a valve seat 87 when the magazine is not associated with the weapon. When the magazine is connected to the weapon, downwardly extending tube 89, as shown in FIG. 9, pushes the valve element 85 downwardly to establish fluid communication through a slot 91 in the sidewall of the tube 89.

The projectile-carrier assemblies are fed upwardly through a pair of channels 93 and into a common channel 95 and then into the receiver assembly of the weapon by the same bolt actuated elevator mechanism used to lift the bottom wall of the propellant supply tank or reservoir 79.

A specific description in the lift mechanism for the magazine is set forth below with reference to FIGS. 22–24.

A strippable top 97 retains the projectiles in place until the magazine is loaded into the weapon.

A number of liquid propellants have been found satisfactory for the weapon of the present invention. They include but are not limited to mono propellants such as hydrazine nitrate composed of 35%, $N_2H_5NO_3$, 5% H_2O and 60% N_2H_4; Monomethyl Hydrazine Nitrate 90%; Ethyl Propyl Nitrate 60/40; Otto Fuel II.

A metal partition 101 in the magazine serves to positively isolate the primers in the projectile-carrier assembly from the propellant in the tank 79 to preclude inadvertent ignition. A suitable strap transfer mechanism can be associated with the elevator strip 101, as shown in FIG. 24.

The receiver assembly 45, as shown in FIG. 9, has a two-part bolt assembly. The bolt assembly includes an outer bolt 103 and an inner bolt 105.

The outer bolt is reciprocal within a bore 107 in the receiver assembly 45 and barrel 43.

The inner bolt 105 is reciprocable within a bore 109 in the outer bolt.

The tube 89 connecting the propellant supply in the magazine also connects a tube or conduit 111 in the receiver assembly through a propellant control valve 113. The forward end of the tube 111 slides within a bore 114 in the outer bolt in trombone fashion during the reciprocation of the outer bolt 103.

A seal 110 seals between the tube 111 and the bore 113.

The forward end of the conduit 116 connects to the combustion chamber 115 through a spring biased one way ball check valve 117 in the forward face of the outer bolt 103.

A seal 119 is carried at the forward end of the outer bolt to seal against the wall 107 of the combustion chamber 115.

The forward end of the inner bolt 105 includes extractor clip 121 which is resiliently biased by a spring 123. The forward ends of the resilient arms of the clip 121 clip over the extraction lip 75 of the carrier to remove the carrier from the bore 109 after firing.

An off center ejector pin 125 in the inner bolt (see FIG. 15) kicks the carrier out through an ejection slot 127 in the outer bolt and in the receiver assembly 45.

A firing pin 129 is reciprocable within a bore 131 in the inner bolt 105 to ignite the propellant igniter 77 in the carrier.

A bolt lock 133, see FIG. 10, is pivoted about a pivot 135 and is spring biased towards the position illustrated in FIG. 10 by a spring 137 to place the forward face of the bolt lock in locking engagement with the rear face 139 of both the outer bolt 103 and the inner bolt 105. A cam 139 moves forward and engages a corresponding cam surface 141 on the bolt lock 133 to pivot the bolt lock against the force of the spring 137 to release the bolt at the end of the firing cycle.

The operation of the weapon thus far described is illustrated in FIGS. 11–16 which illustrate respectively projectile transfer, projectile ramming, propellant loading, combustion, and the carrier ejection.

The automatic firing cycle is initiated with the bolt in the open position after the firing of a burst. This eliminates cook-off of a round in the hot breech. Propellant isolation is effected by supplying the propellant through the bolt. This allows insertion of a thermal barrier between the barrel and receiver group, effectively isolating the hot barrel from those components in direct contact with liquid propellant.

There is little likelihood of dynamic cook-off of propellant during loading. Static cook-off, however, can be a problem, as it is with caseless solid propellant ammunition.

It is therefore an important feature of the present invention that the propellant supply is isolated from those hot surfaces which might effect ignition of a chambered ground or ignition in the propellant supply.

When released by the trigger operated sear, the bolt picks up a carrier and projectile from the clip and inserts the assembly into the bolt bore. The bolt-operated elevator mechanism of the magazine, described above, effects this action by lifting the entire string of projectile-carrier assembly described above.

The flat 73 on the carrier extractor ram aligns the carrier.

The bolt is then driven forward, as illustrated in FIG. 12, by the operating mechanism until the projectile 51 engages the bore opening of the weapon at the forward end of the combustion chamber 115.

The propellant valve 113 is then opened, as illustrated in FIG. 13. This allows propellant supply pressure to (1) seat the projectile, (2) separate the projectile carrier from the projectile within the bolt, and (3) fill the combustion chamber 115 with propellant as the bolt is moved rearward, as illustrated in FIG. 13, to its firing position.

During this phase of operation the propellant flows past the one-way ball check valve 117 and enters the carrier through the opening between the fingers or clips 63 in the carrier wall. The propellant flows through the propellant flow grooves 59 in the projectile 51 and acts

on the rear face 67 of the projectile T1 and the forward inner face 69 of the carrier.

When the firing chamber 115 is filled, the bolt is locked in its rear position by the lock 133 (see FIG. 10).

The firing pin 129 is released, and the firing pin strikes the percussion primer 77, igniting the liquid propellant charge in the combustion chamber 115.

After projectile exit, the bolt is opened, the spent projectile carrier is ejected as illustrated in FIG. 15, and a subsequent cycle is initiated as long as the trigger is depressed.

The weapon may also be operated in a semi-automatic mode if a burst has not been fired recently. In the semi-automatic mode the man firing the gun hand operates an operating handle to fill the firing chamber 115 with propellant and to position the parts in their relative positions as assumed at the end of propellant loading as illustrated in FIG. 13. In this case the weapon is in effect cocked and ready to fire when the trigger is pulled and the firing pin is released to engage the igniter 77 as illustrated in FIG. 14. The weapon can continue to operate in the semi-automatic mode as long as the chamber 115 does not become hot enough to allow static cook-off.

A thermostatic element can be included in the weapon to override semi-automatic operation when the chamber housing is too hot to allow semi-automatic operation from a filled chamber.

As illustrated in FIG. 17 the drag coefficient for the reentry body projectile is quite low, especially in comparison to projectiles having configurations which are presently being used. The small bore liquid propellant gun of the present invention permits the use of this reentry body configuration by providing the requisite high velocity for aerodynamic stabilization. The weapon of the present invention can produce high velocity (as a practical matter) because the liquid propellant combustion does not heat the barrel as much as solid propellant combustion. The cooler burning characteristics of the liquid propellant are graphically illustrated in FIG. 16. This figure shows the envelope of peak bore surface temperatures during eight round bursts of liquid and solid propellant ammunition.

A weapon constructed in accordance with another embodiment of the invention is illustrated in FIGS. 18, 19 and 20.

The weapon shown in FIGS. 18 and 19 embodies two important features.

A reciprocating combustion chamber housing slides over the rear end of the barrel and replaces the conventional bolt mechanism.

The magazine is a completely self-contained magazine which incorporates a propellant pump, a chamber high pressure inlet valve and a clip of projectile-carrier assemblies.

When the reciprocable combustion chamber housing of the embodiment of the weapon shown in FIG. 18 is fully forward, the combustion chamber is completely eliminated. As the housing moves to the rear, the combustion cavity is formed in a manner which eliminates ullage.

This embodiment of the present invention achieves a low length to diameter ratio for the combustion chamber. This minimizes receiver length and improves chamber wall cooling due to the liquid annulus remaining at the time of initiation.

This reciprocating housing construction permits the use of a static lock for the combustion chamber.

Combustion loads are not carried through a receiver but are carried through the static members linking the barrel to the chamber.

It provides convenient means of thermal isolation for the chamber.

It permits ready increase of velocity level by using a longer chamber and stroke.

Propellant passages in the receiver mechanism are eliminated which simplifies the mechanism, eliminates voids and eliminates propellant filled passages which could transmit flame from the combustion chamber to the propellant supply in the magazine.

As illustrated in FIG. 18 a combustion chamber housing 161 slides back and forth on the outer surface 163 of the end of the barrel 43.

The housing 161 is shown in its rearward most position in FIG. 18 ready for firing. The combustion chamber housing 161 and the bolt 105 are held in this position by a static or stationary lock 165. The lock 165 abuts the back face of the housing 161. The lock 165 includes an inner recess 167 which engages a radially projecting tang 169 of the bolt. The tang 169 is rotated into blocking engagement with the recessed surface 167 of the lock.

A seal 171 at the forward end of the housing 161 seals between the housing 161 and the barrel surface 163.

Liquid propellant is admitted to the combustion chamber 151 through a port 173 in the housing 161.

A valve element 175 controls the admission of liquid propellant through the port 173. The valve element 175 is reciprocable within a bore 177 in the housing 161, and a vent 179 vents the forward end of the bore 177.

As described below, a strap transfer mechanism 181 is operated by movement of the bolt to lift a toothed strap 101 to elevate the bottom wall of the propellant tank 79 and the bottom wall of the clip for the projectiles on each cycle of operation.

FIGS. 22 and 23 illustrate schematically operation of the strap transfer mechanism 181. Two straps 101 are provided, one to raise the projectiles and the other to compress the propellant supply bellows.

The strap transfer drive tang 184 engages a slot in the bolt which causes reciprocation of drive tang 184. During rearward motion of the tang its teeth engage corresponding teeth on plastic strap 101 causing it to be transported to the rear and at the same time rotating take up reel 188. When the bolt moves forward, holding clutch 186 prevents relaxation of the tension on strap 101. Excess tension in the strap is prevented by slipping action between the drive teeth of tang 184 and strap 101 which is controlled by the spring load on holding clutch 186.

FIG. 19 illustrates the manner in which the projectile-carrier assemblies are fed into position in the front of the bolt.

A pair of resilient clips at the upper end of the passage 95 holds the uppermost projectile in position until the forward movement of the bolt pushes the projectile carrier into the combustion chamber.

A tang or cam follower 183 on the bolt engages a groove or cam path 185 to control rotation of the bolt during reciprocating movement.

As noted above, the flow of propellant to the combustion chamber 51 is under the control of a valve ele-

ment 175. This valve element 175 is a part of a pumping assembly which is indicated generally by the reference numeral 191 and which is an integral part of the magazine 47.

The pumping assembly 191 includes three operating elements. These elements are a reciprocable outer housing 193, a piston 195 and the valve element 175.

The piston 195 slides within a bore 197 within the outer housing 193, and is connected to a piston rod 199 which extends outwardly through a sealed opening in the rearward end of the outer housing 193.

The valve element 175 is connected to a rod 201 which extends through a seal in the piston 195 and which is reciprocable within a bore 203 in the rod 199.

The outer housing 193, the rod 199 and the rod 201 each have an upwardly extending lip which is releasably engaged by an operating element 205, 207 and 209 respectively of the weapon.

The rear face of the valve element 175 has a seal element 211 which engages a forward annular face of the outer housing 193 in sealing relationship in the position illustrated in FIG. 18.

The valve element 175 also includes sealing members 213 and 215. These sealing elements are high pressure seals which prevent any flow out the combustion chamber 151 during combustion.

Propellant is drawn into the chamber formed in the bore 197 in front of the piston 195, during one phase of operation of the weapon, through a conduit 217 in the outer housing 193 and past a spring biased one-way ball check valve 219. The conduit 217 has an extension 217A which compensates for reciprocation of the conduit 217 within the reservoir 79 to prevent an unequal displacement of volume during reciprocation.

As in the embodiment of the invention described with reference to FIGS. 9–15, the embodiment illustrated in FIGS. 18 and 19 can operate in two modes — the automatic mode for firing bursts and semiautomatic mode.

The automatic mode is started with the bolt 105 fully retracted behind the projectile assembly. The reciprocating combustion chamber housing 161 is fully rearward with the rear face 166 in abutment with the lock 165.

At this point the strap 101 has operated to lift the bottom of the magazine to position a projectile-carrier assembly in front of the bolt.

The bolt 105 is then moved forward. This transfers the projectile-carrier assembly forward until the projectile 51 is seated in the barrel and the elastomer seal 57 engages the inside of the barrel to form a liquid seal.

Locking and unlocking of the bolt is controlled by the action of the cam path 185 on the bolt cam follower 183. Forward and backward movement of the cam slide 160 is controlled by the gas piston push rod 162. This camming action rotates the bolt prior to forward or backward movement of the bolt assembly. A manual override 164 is provided to permit hand operation of the bolt in event of misfire.

In a typical firing cycle the gas piston push rod 162 is driven to the rear by combustion gasses as the projectile passes by a gas port near the muzzle. Rearward motion of the push rod 162 and cam slide 160 rotate the bolt cam follower 183 counterclockwise (viewed from the rear) to disengage the bolt tang 169 from the bolt lock inner recess 167 allowing the bolt to move to the rear, extracting and ejecting the spent projectile carrier. At its rearmost position the bolt picks up a new projectile and carrier assembly and during forward motion loads this assembly into the combustion chamber housing. Continued forward motion of the cam slide 160, rotates the bolt clockwise and carries the combustion chamber housing 161 forward until barrel surface 44 is in abutment with housing surface 160 at which time the pumping cycle is initiated as described above.

FIGS. 21A–D show another embodiment of a projectile-carrier assembly incorporating a coacting tang and slot construction for positive extraction in the event of misfire. The propellant-flow ports and grooves are omitted in FIGS. 21A–D for clarity of illustration but are the same as in the embodiment shown in FIGS. 2–5.

As best shown in FIG. 21B, the carrier has a tang 70 the end of a finger 63.

As best shown in FIG. 21D the projectile has a slot 60 with a recess 62.

In normal operation the tang 70 does not engage the recess 62. The spring action of the fingers 63 hold the projectile in place during loading.

If there is a misfire, the normal counterclockwise rotation of the bolt causes the tang 70 to be engaged in the recess 62 when the carrier is reconnected to the unfired projectile.

The tang 70 is never engaged in the recess 62 except in the event of a misfire. The normal loading and locking movement of the bolt is clockwise.

As the bolt is moved forward, the outer housing 193 of the pumping assembly 191 is also moved forward with the valve element 175. This permits propellant to flow through the passage 217 and pass the check valve 219 into a chamber which is formed between the front face of the piston 195 and the rear inner face of the forward part of the valve of the outer housing 193.

The forward movement of the outer housing 193 and the valve element 175 is then discontinued while the forward movement of the valve element 175 is continued. The valve element 175 jogs forward enough to uncover the port 173. Propellant can then flow from the chamber in front of the piston 195 through the bore 231 in the center part of the forward end of the outer housing 193 and through the port 173 and into the combustion chamber 151.

The outer housing 193 is then moved to the rear by the actuating mechanism 205 while the piston 195 is held stationary. This pumps the propellant into the combustion chamber 151. This in turn moves the reciprocating combustion chamber housing 161 to the rear and separates the carrier 53 from the projectile 51.

When the rearward movement of the pump outer housing 193 and the combustion chamber housing 161 has been completed, and the housing 161 is in abutment with the stationary lock 165, actuating element 209 then pulls valve element 175 rearward to the position illustrated in FIG. 18 in which the high pressure seals 213 and 215 seal off any fluid flow through the port 173.

The bolt 105 is moved to the rear with the rearward movement of the housing 161.

At this point the weapon is ready for firing, and firing is accomplished by the hammer striking the firing pin 129 to force the forward end of the firing pin into engagement with the back face of the carrier 53 to ignite the igniter 77.

A conventional gas operated linkage connected to the bolt gives the bolt a kick to the rear when the projectile passes the gas operator.

An off center ejector pin in the bolt, like the pin 125 shown in FIG. 15 tumbles the spent carrier out through an ejection slot.

In the event of a misfire the valve element 175 is moved forward to uncover the port 173, and a manually actuated misfire mechanism pushes the housing 161 forward to pump out the propellant from the combustion chamber 151.

The bolt 105 is rotated with respect to the carrier 58 to engage the extraction clips of the bolt in the slot of the carrier to produce a positive grip between the bolt and the carrier. The bolt is then pulled back to extract the carrier and the projectile 51, and the entire reengaged carrier and projectile assembly is ejected through the ejection slot at the end of rearward movement of the bolt.

In the semi-automatic mode the parts are manually actuated for the first shot to the relative positions illustrated in FIG. 18 so that the weapon is ready to fire when the trigger is pulled.

As described above, with reference to the first embodiment of this invention, a thermostatic element can be provided to override the semi-automatic operating mechanism when the chamber housing is too hot to allow semi-automatic operation from a filled chamber.

To remove the magazine 47 from the weapon illustrated in FIG. 18, a clip release is actuated to move the outer housing 193, the piston 195 and the valve element 175 to the rear and to release the magazine housing from the receiver 45.

It is an important feature of the embodiment of the present invention shown in FIG. 18 that propellant passages in the receiver mechanism are eliminated. The only free volume is the connection from the combustion chamber 151 to the bore 177 through the relatively small port 173.

The high pressure seals 213 and 215 are replaced each time a new magazine is used.

The flat seal 211 provides positive propellant isolation, and there is always an atmospheric vent after the high pressure seal 215 and before getting to the propellant in the reservoir 79.

While we have illustrated and described the preferred embodiments of our invention, it is to be understood that these are capable of variation and modification, and we therefore do not wish to be limited to the precise details set forth, but desire to avail ourselves of such changes and alterations as fall within the purview of the following claims.

We claim:

1. A projectile-carrier assembly for a liquid propellant gun comprising,

a projectile having a sidewall,

propellant flow passage means in a sidewall of the projectile at the rear end of the projectile,

a carrier having a sidewall,

said carrier having an open ended front part for receiving the rear end of the projectile.

connecting means on the carrier engageable with the projectile to connect the carrier and projectile so the projectile can be transported by the carrier,

and opening means in the sidewall of the carrier associated with the passage means in the projectile for permitting the flow of liquid propellant through the opening means and passage means and between the projectile and the carrier to disconnect the connecting means and to separate the carrier from the projectile after the projectile has been placed in firing position in the gun.

2. A projectile-carrier assembly as defined in claim 1 wherein the connecting means include resilient clips on the carrier and recesses on the projectile for receiving the clips.

3. A projectile-carrier assembly as defined in claim 1 including a flat on the carrier for aligning the carrier and projectile with the bolt of the gun.

4. A projectile-carrier assembly as defined in claim 1 including a radially extending lip at the radial end of the carrier which can be engaged by a clip on the bolt to extract the carrier from the gun.

5. A projectile-carrier assembly as defined in claim 1 including an elastomer seal extending circumferentially around the projectile for forming a fluid-type seal with the bore of a gun when the projectile is placed in firing position in the gun.

6. A projectile-carrier assembly as defined in claim 1 including an elastomer seal extending circumferentially around the carrier for forming a fluid-tight seal with the rear end of the firing chamber of the gun.

7. A projectile-carrier assembly as defined in claim 1 including a percussive igniter in the carrier.

8. A projectile-carrier assembly as defined in claim 1 wherein the projectile has a reentry body configuration and which is an aerodynamically stabilized shape.

* * * * *

United States Patent [19]

Groen et al.

[11] **4,161,904**

[45] **Jul. 24, 1979**

[54] **LIQUID PROPELLANT MODULAR GUN INCORPORATING HYDRAULIC PRESSURIZATION OF THE CASE**

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[73] Assignee: **Pulsepower Systems, Incorporated**, San Carlos, Calif.

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[51] **Int. Cl.**² **F41F 1/04**

[52] **U.S. Cl.** **89/7**; 89/11

[58] **Field of Search** 89/7, 9, 11, 12, 172, 89/185

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Primary Examiner—David H. Brown

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[57] **ABSTRACT**

A liquid propellant modular gun has a main cam which is driven at a multiple of the gun firing rate and which has internal cam surfaces operatively associated with the bolt while the bolt is driven forward to load and fire and backward to accept another projectile.

The gun incorporates a control cam driven at the gun firing rate and effective to unlock the bolt after firing of a projectile so that the bolt can be returned to its rearward position under the control of the main cam.

The main cam acts to time all the remaining mechanisms of the gun to the bolt motion.

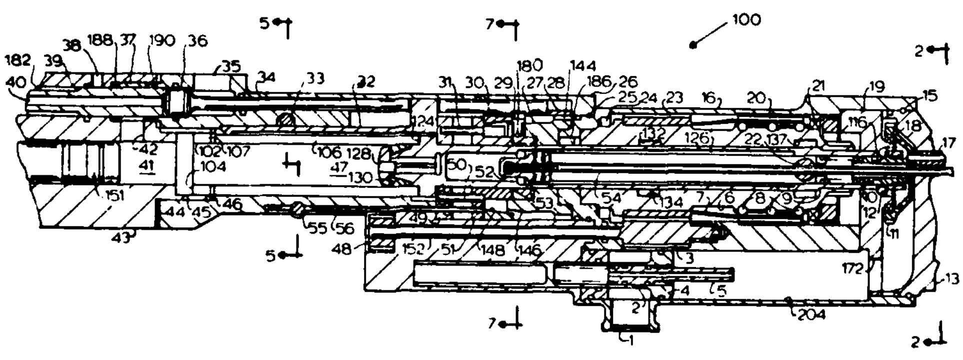
The accelerating force for the bolt is provided by hydraulic pressure applied directly to the bolt area.

Energy stored in the bolt from the force of the accelerating hydraulic pressure is converted into rotary energy and is stored in the main cam and other rotating devices geared to the main cam.

The stored rotary energy in the main cam is used in combination with residual gas pressure remaining in the gun barrel for a part of the bolt return stroke to accelerate the bolt rearward.

Energy losses, including those caused by hydraulic pressure drop, friction and windage, are made up by a pumping system receiving its energy from the gas pressure added to the gun as a part of the firing of each projectile.

32 Claims, 9 Drawing Figures



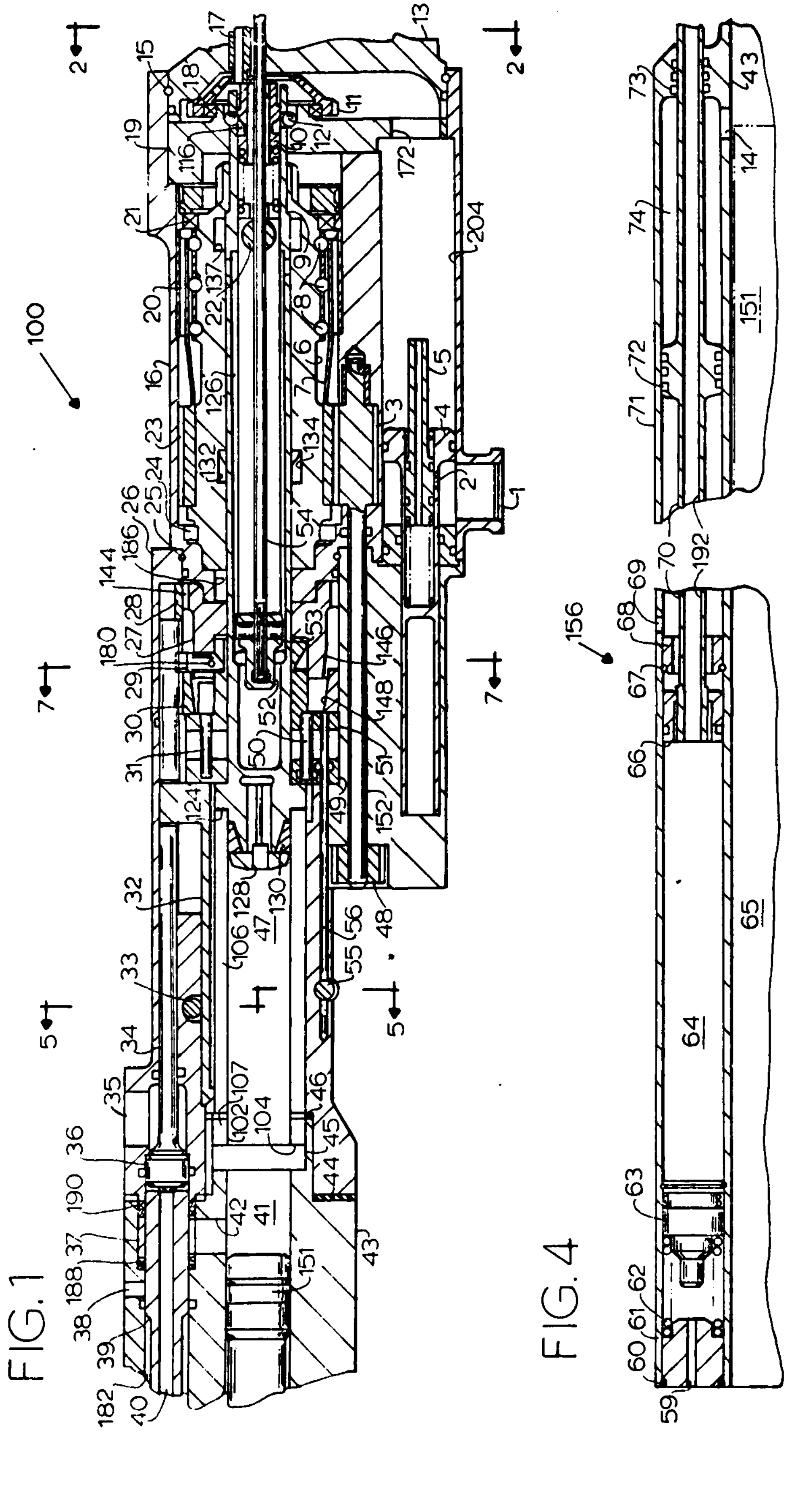


FIG. 1

FIG. 4

FIG.2

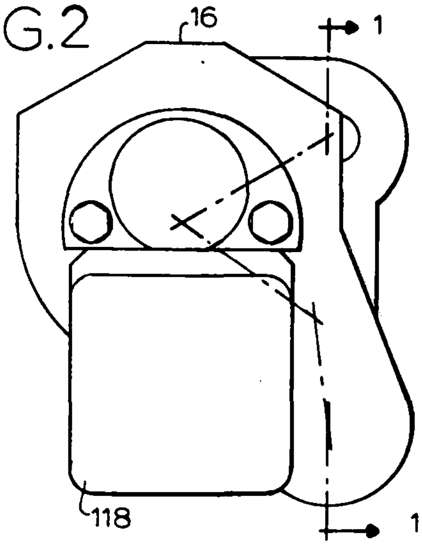
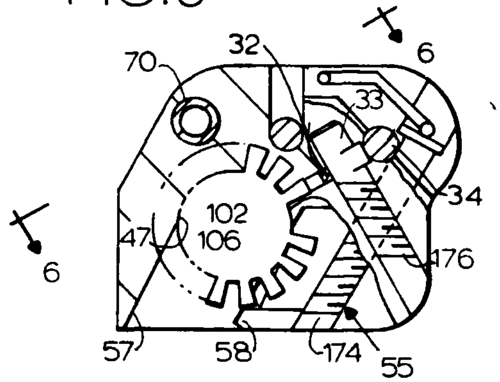


FIG.5



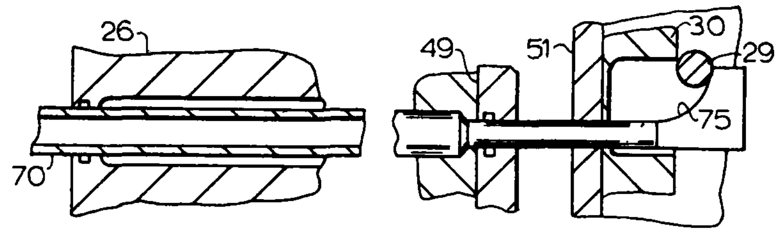
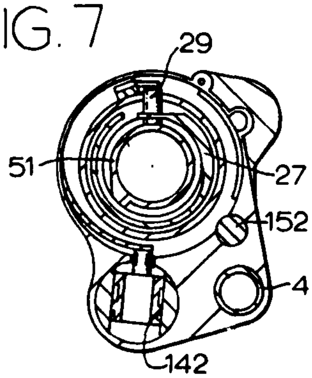


FIG.6

FIG.7



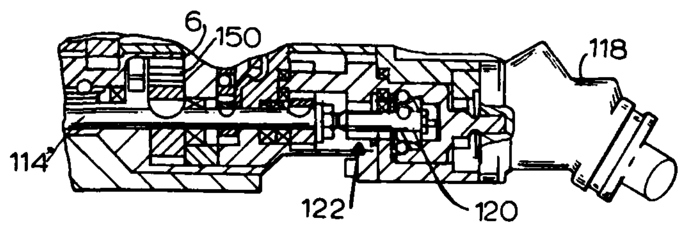
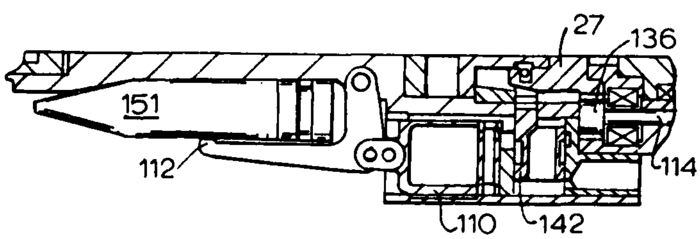


FIG.9

FIG 8



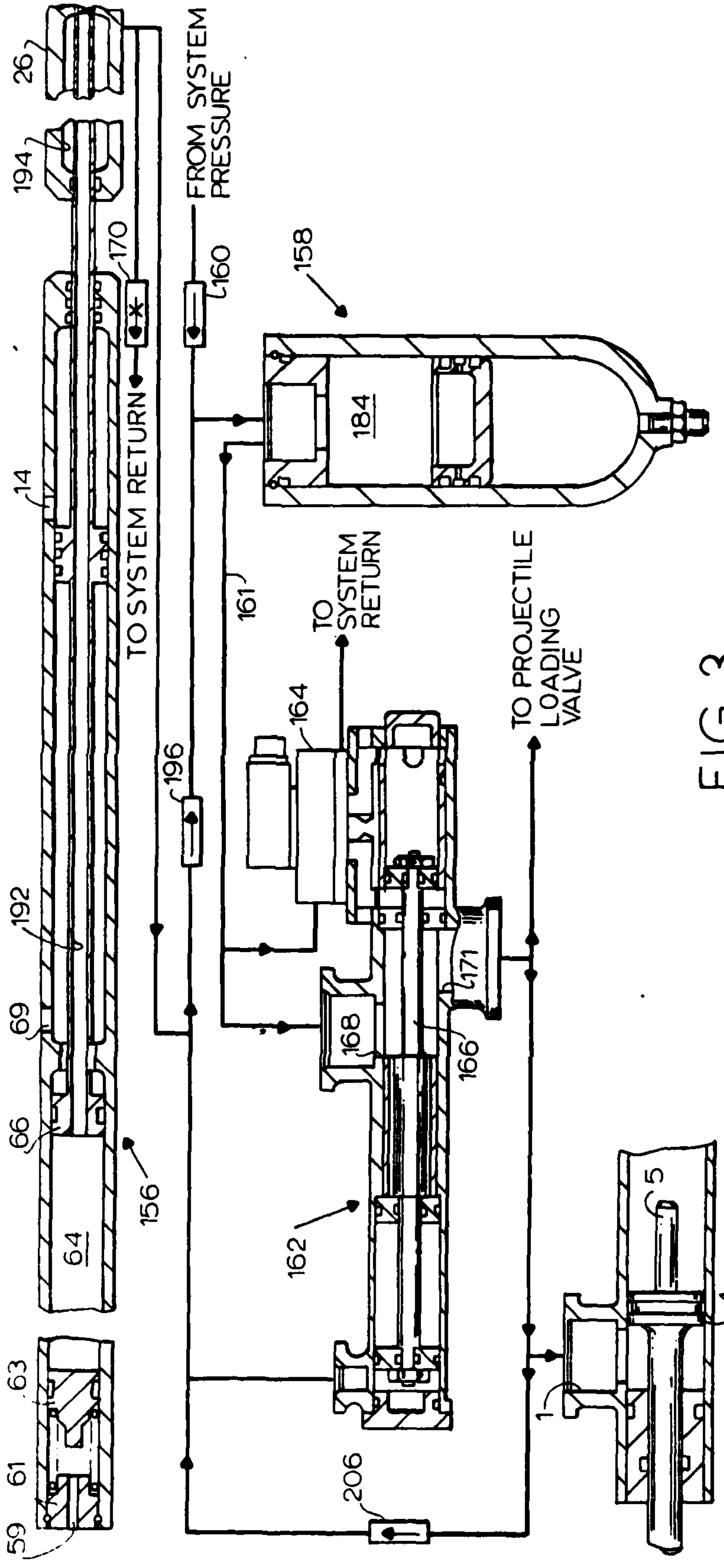

26
194
170
FROM SYSTEM PRESSURE
160
158
184
TO SYSTEM RETURN
14
161
TO SYSTEM RETURN
TO PROJECTILE LOADING VALVE
164
196
192
69
168
171
166
66
156
64
162
5
4
63
61
59
206
1

FIG. 3

LIQUID PROPELLANT MODULAR GUN INCORPORATING HYDRAULIC PRESSURIZATION OF THE CASE

CROSS REFERENCES TO RELATED APPLICATIONS

This invention relates to a liquid propellant gun of the kind disclosed in issued U.S. Pat. Nos. 3,800,657; 3,915,057; 3,949,642; 3,919,922; and 3,998,129 to Broxholm et al. and pending U.S. patent application Ser. No. 616,822 filed Sept. 25, 1975 by Elmore et al and now U.S. Pat. No. 4,062,266 (all assigned to the same assignee as the assignee of this application).

BACKGROUND OF THE INVENTION

This invention relates to a modular liquid propellant gun of the kind in which liquid propellant is burned in a combustion chamber to fire a projectile from the gun.

The liquid propellant guns disclosed in the five issued U.S. Patents and pending U.S. patent application referred to above are representative of the prior art, and the present invention relates to certain improvements in a liquid propellant gun of this general kind.

SUMMARY OF THE INVENTION

The liquid propellant gun of the present invention is a hydraulically operated, externally-driven gun constructed in modular form. A main cam serves to time all operations to the bolt motion, to decelerate the bolt during its loading stroke and to accelerate the bolt during its opening stroke.

The gun mechanism is so housed that it can be grouped in multiple units, either in a circular or flat configuration, to give a multi-barrel gun.

A hydraulic motor is used on each module to provide rotary power for driving the gun mechanism. The motor drives a main cam and a control cam by means of gears off a jackshaft.

The main cam operates at a multiple of the gun firing rate and has internal cam grooves of the Yankee screwdriver configuration which are associated with a cam follower on the bolt during forward motion of the bolt to load and fire and during backward motion of the bolt to accept another projectile.

The bolt is locked at the end of the forward motion by rotating the bolt to place locking lugs on the head of the bolt behind mating lugs in the barrel.

The bolt is maintained in this locked position throughout the propellant loading and firing portion of the cycle and is then unlocked by a control cam rotating in the reverse direction from the main cam. The control cam operates at the gun firing rate and urges the bolt cam follower pin into the return groove of the main cam.

The main cam also has a rest groove in which the bolt cam follower pin rides when the gun is not firing.

The gun repeats the firing operation (loading a new projectile into the bolt pathway as soon as the bolt reaches its fully retracted position) in an automatic mode of operation unless the bolt is locked in the fully retracted position.

In the present invention the main cam acts to time all the mechanisms of the gun to the motion of the bolt.

The main cam also serves, to some extent, to drive the bolt during certain portions of the movement of the bolt, but the primary function of the main cam is synchronization of the bolt movement with other gun mechanisms.

The power required to accelerate and to drive the bolt and projectile forward into the gun barrel is quite high during automatic operation of the gun. To obtain this high peak power efficiently the present invention applies hydraulic pressure directly to the bolt area. When the bolt is unlocked, this hydraulic pressure drives the bolt and projectile forward so that the main cam, during this part of the cycle of operation, does not provide the accelerating force for the bolt and projectile.

The bolt must be slowed to a low velocity at the end of the forward stroke, and the main cam is used to provide this slowing of the bolt during the last half of its stroke. This result is obtained by increasing the cam groove angle so that the energy stored in the bolt from the accelerating hydraulic pressure is transferred through the bolt follower to the main cam and is converted into rotary energy which is stored in the main cam and all the other rotating devices geared to the main cam.

The firing rate of the gun is dependent upon the average speed of the main cam and the control cam geared to it. In one particular embodiment of the present invention, the main cam operates initially at 3,000 rpm and the control cam operates initially at 600 rpm to provide a firing rate of 1,000 rounds per minute.

The hydraulic pressure used to drive the bolt forward not only smooths cyclic peak loads, but it also supplies lubrication to the entire drive assembly of the gun since the entire mechanism is sealed in an oil bath by the present invention.

After firing, the bolt cam follower is rotated to the unlocked position by a control cam as noted above.

At this point, the present invention utilizes residual gas pressure in the barrel to force the bolt rearward and to position the bolt cam follower in the return groove in the main cam.

The stored rotary energy in the main cam is then used, in addition to the residual gas pressure remaining in the barrel, for a part of the stroke to accelerate the bolt rearward.

The energy stored in the main cam would return the bolt to its starting position after it is unlocked if the losses (including those caused by hydraulic pressure drop, friction and windage and the kinetic energy in the projectile) were negligible. However, these losses are large enough to require a significant addition of power to the hydraulic system from an external power source. In accordance with the present invention, a gas operated hydraulic pumping system (which receives its energy from the gas pressure added to the gun as a part of the firing of each projectile) is employed to provide the additional energy required during each firing cycle rather than requiring the main hydraulic system power source to supply it.

The present invention also embodies a timing cam driven at the same speed as the control cam. The timing cam serves as a lock-out device to allow the bolt release only during the appropriate portion of the cycle. The timing cam synchronizes the bolt unlock operation with the control cam position. That is, since the main cam turns at a multiple of the gun firing rate, the forward groove of the main cam passes the bolt cam follower a number of times before the timing for the release of the bolt is correct with respect to the control cam. The timing cam provides the required synchronization of

the bolt release into the forward groove of the main cam.

A torsion bar is used to provide a constant locking torque on the bolt to effect the necessary radial motion of the bolt in a sufficiently short time. The torsion bar provides a high spring force to rotate the bolt into a locked position at the end of the bolt forward stroke.

A single valve arrangement is used for controlling the flow of propellant to the combustion chamber of the gun. The valve is associated with a projectile sensor mechanism in a manner such that the propellant valve is maintained closed until a projectile has actually entered the gun as determined by the actuation of the projectile sensor mechanism.

The propellant valve must then be opened rapidly. The valve is opened by the forward motion of the bolt, to provide the required fast opening of the valve, and is held opened during the propellant filling portion of the cycle by a cam pin in the control cam. The propellant valve also provides isolation of the propellant supply from the gun combustion chamber during firing. The projectile sensor mechanism forces a sliding member to the end of its travel against a spring load as a projectile enters the gun from the feed belt. This motion forces a sear hook attached to the propellant valve into the path of a locking lug on the bolt head. The forward motion of the bolt then can engage the propellant valve and open it.

The projectile sensor mechanism thus ensures that, if no projectile enters the gun, no propellant is admitted to the gun.

The projectile sensor mechanism is also effective to prevent the gun module from being disabled by a misfire cam if no projectile enters the gun from the feed belt.

The present invention incorporates a multi-purpose misfire detection mechanism which uses the gas pressures added to the gun upon the firing of each projectile for two purposes—to pump make up fluid and to operate the misfire detection.

As noted above, these gas pressures are used to pump hydraulic fluid to make up energy losses.

The present invention uses a piston and rod assembly as part of this pumping mechanism.

The piston and rod assembly also operates a disable cam to disable the gun module in the event of a misfire.

The mechanism used to lock the bolt in its most rearward position incorporates a ball lock device which is controlled by a plunger operated by a solenoid or by the application of hydraulic pressure directly to the plunger.

The belt which feeds projectiles and which surrounds the gun module or gun modules is caused to rotate as soon as the gun module or modules are put into the ready condition. The drive for this mechanism is obtained from the same hydraulic motor (or motors) which drives the individual gun module (or associated gun modules).

The drive connection between the hydraulic motor and the belt includes harmonic drive gearing to provide a large gear reduction with a minimum of mechanism bulk and weight.

The hydraulic motor in each gun module drives the main cam of the gun module, as described above; and the main cam is geared to an output shaft through the harmonic drive gearing. The shaft in turn is geared to the belt containing the projectiles.

Thus, the belt surrounding the modules serves to synchronize the firing of the modules and serves also to drive the projectile feed to the gun modules.

Liquid propellant gun apparatus and methods which incorporate the structure and techniques described above and which are effective to function as described above constitute specific objects of this invention.

Other and further objects of the present invention will be apparent from the following description and claims and are illustrated in the accompanying drawings which, by way of illustration, show preferred embodiments of the present invention and the principles thereof and what are now considered to be the best modes contemplated for applying these principles. Other embodiments of the invention embodying the same or equivalent principles may be used and structural changes may be made as desired by those skilled in the art without departing from the present invention and the purview of the appended claims.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a fragmentary side elevation view in cross section of a liquid propellant gun constructed in accordance with one embodiment of the present invention. The section of FIG. 1 is taken along the line and in the direction indicated by the arrows 1—1 in FIG. 2.

FIG. 2 is an end elevation view of the gun shown in FIG. 1 and is taken in the direction indicated by the arrows 2—2 in FIG. 1.

FIG. 3 is a schematic, partly in cross section, of a hydraulic system associated with the gun of FIG. 1.

FIG. 4 is a fragmentary side elevation view in cross section of a muzzle switch actuator physically incorporated in the gun module of FIG. 1 but also shown as a part of the hydraulic system of FIG. 3.

FIG. 5 is a cross section view taken along the line and in the direction indicated by the arrows 5—5 in FIG. 1. FIG. 5 is partly broken away to show details of a projectile presence sensor lug 58 and helical rack 55.

FIG. 6 is a fragmentary cross section view taken along the line and in the direction indicated by the arrows 6—6 in FIG. 5. FIG. 6 shows details of a misfire detection cam 75 and its association with the gas operated rod 70 of FIG. 4.

FIG. 7 is an elevation view in cross section taken along the line in the direction indicated by the arrows 7—7 in FIG. 1.

FIG. 8 is a fragmentary side elevation view in cross section through a portion of the gun shown in FIG. 1 and shows details of the drive to the control cam and the hydraulic piston and hammer assembly for loading projectiles.

FIG. 9 is a fragmentary side elevation view in cross section taken along the same plane as FIG. 8 showing details of the drive to the main cam.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

A liquid propellant gun module constructed in accordance with one embodiment of the present invention is indicated generally by reference numeral 100 in FIG. 1.

The liquid propellant modular gun 100 is a hydraulically driven, cam synchronized mechanism that fires a caseless, liquid monopropellant round. The gun module construction provides for flexible, modular installation with several modules grouped to use a single feed system. The gun module can be utilized as an in-row grouping or as clustering in a circular pattern.

Each module is self-contained and is independent of all others when used in a multi-module configuration, and synchronization between modules is obtained by gearing each module to a common projectile feed system. In the multi-module configuration the modules are timed so that they fire successively and at equal intervals, thus providing integrated, multi-barrel operation. The gun of the present invention includes a misfire detection feature that disables one module in case of a misfire while permitting the remaining modules in a banked row or cluster to continue to fire.

The gun module **100** includes as principal components a barrel **43**, a barrel extension **26** and a drive assembly housing **16** which supports the components in the drive assembly.

The gun module **100** also includes the following listed numbered elements, each of which is described in greater detail in the text following the listing.

DRAWING REFERENCE NUMERAL	GUN MODULE STRUCTURAL ELEMENT	DRAWING REFERENCE NUMERAL	GUN MODULE STRUCTURAL ELEMENT
1.	Hydraulic system pressure port	18.	Timing cam bearing
2.	Transfer piston valve port	19.	Support
3.	Harmonic drive output pinion	20.	Harmonic drive internal gear
4.	Transfer piston	21.	Main cam rear bearing
5.	Transfer piston valve		
6.	Main cam	22.	Bolt cam follower
7.	Flexspline	23.	Flexspline output gear
8.	Harmonic drive elliptical cam balls		
9.	Bolt	24.	Main cam forward bearing
10.	Bolt lock piston		
11.	Timing cam	25.	Retainer ring
12.	Bolt lock balls	26.	Barrel extension
13.	Drive chamber end	27.	Control cam
14.	High pressure gas inlet port	28.	Propellant valve arc cam
15.	Retainer ring	29.	Control cam pin
16.	Drive assembly housing	30.	Control cam lock ring
17.	Bolt lock release plunger		
31.	Propellant valve disable push pin	49.	Drive chamber plug
32.	Propellant valve sear hook	50.	Pin cam actuating rod
33.	Propellant valve sear hook cam	51.	Pin cam
34.	Propellant valve stem	52.	Torsion bar head
35.	Propellant inlet port	53.	Torsion bar pins
36.	Propellant valve head	54.	Torsion bar
37.	Blocking slide sleeve	55.	Projectile sensor
38.	Vent port	56.	Pin cam locking rod
39.	Blocking slide		
40.	Blocking slide vent port	57.	Projectile entry port
41.	Gun chamber	58.	Projectile sensor [illegible]
42.	Gun chamber propellant inlet port		
43.	Barrel	59.	Vent port
44.	Insulation	60.	Retainer ring
45.	Bolt locking lug relief groove	61.	Gas pump spring retainer plug
46.	Insulation	62.	Gas pump spring
47.	Projectile receiver bore in barrel extension	63.	Gas pump override hydraulic piston
48.	Projectile drive gear train pinion	64.	Gas pump hydraulic fluid chamber
65.	Rifled barrel	107.	Guide grooves for the bolt lugs in the barrel
66.	Gas pump hydraulic		

-continued

DRAWING REFERENCE NUMERAL	GUN MODULE STRUCTURAL ELEMENT	DRAWING REFERENCE NUMERAL	GUN MODULE STRUCTURAL ELEMENT
	fluid piston		
67.	Retainer ring	108.	Projectile sensor torsion bar spring
68.	Gas pump piston stop		
		109.	Projectile sensor spring arm
69.	Vent port		
70.	Gas pump piston rod	110.	Projectile loading piston
71.	Gas pump piston	112.	Projectile loading hammer
72.	Gas pump piston sealing rings	114.	Jackshaft
73.	Gas pump rod sealing rings	116.	Bolt rest position locking means
74.	Gas pump high pressure gas chamber	118.	External rotary hydraulic drive motor
75.	Disable cam	120.	Overriding clutch
100.	General reference to the liquid propellant modular gun module	122.	Gearing
102.	Bolt locking lugs in barrel	124.	Locking lugs on the bolt
104.	Bolt lug locking surfaces in the barrel	126.	Grooves for torsion rod pins
106.	Bolt lug slideways for bolt lugs in the barrel extension	128.	Precombustion chamber
130.	Chamber breech seal	161.	Conduit
132.	Rearward groove for bolt cam follower	162.	Sequence valve
134.	Forward groove for bolt cam follower	164.	Selector valve
136.	Driving pinion for control cam	166.	Sequence valve spool
137.	Rear rest groove for bolt cam follower	168.	Inlet port
		170.	Restrictor check
142.	Control valve for projectile loader	171.	Outlet port
144.	Gear on control cam	172.	Passageway
146.	Locking taper	174.	Helical rack
148.	Locking taper	176.	Helical gear teeth
150.	Idler gear		
151.	Projectile	180.	Cantilever spring
152.	Shaft		
156.	Muzzle switch actuator	182.	Chamber
158.	Gun system accumulator	184.	Chamber
160.	Check valve	186.	Groove
190.	Metalic rings		
192.	Gas pump fluid passageway		
194.	Gas pump fluid exit cavity		
196.	Check valve		
204	Transfer piston bore		
206.	Check valve		

The barrel 43 provides 60 or more calibers of projectile travel and includes a combustion chamber 41, a propellant fill port blocking slide 39 with its hydraulic spring, an optional water purge valve (not illustrated, but basically like the purge valve illustrated in FIGS. 26, 27 and 28 of the above referred to pending U.S. Pat. application Ser. No. 616,822), breech closure locking lugs 102 having bolt locking surfaces 104, and a gas inlet port 14 near the muzzle communicating with a sensing piston 71.

The barrel 43 is attached to the barrel extension 26 by means of three, close fitting, self-locking pins (not illustrated) which provide a quick disconnect means to remove the barrel and to thermally isolate the barrel from the remainder of the gun by providing either an air gap between the barrel and the barrel extension or insulation 44 and 46.

Since the locking lugs are a part of the barrel 43, breech loads caused by combustion chamber pressure are absorbed by the barrel 43 and are not transmitted to the rest of the mechanism. This permits a lightweight structure for the remaining parts of the gun since the remaining parts must only support their own dynamic and fluid pressure loads.

The barrel extension 26 contains slideways 106 for the bolt 9, the propellant filling valve 36, the projectile presence sensor 55 with its torsion bar spring 108 and arm 109, and the projectile loading means 110 and 112. In addition, the barrel extension 26 provides a housing for a control cam 27, a disable cam mechanism 75, and a support for the projectile feed mechanism which includes a projectile feed belt (not illustrated, but basically like that shown in FIGS. 2, 5, and 31 through 39 of the above noted pending patent application Ser. No. 616,822).

Drive assembly housing 16 contains all the mechanisms for driving the gun. These include a main cam 6, the gearing 3, 23, 7 and 8 for driving the projectile feed system, the transfer mechanism, including a transfer piston 4 for supplying hydraulic pressure to drive the bolt 9 forward, the jackshaft 114 for driving the main cam 6 and the control cam 27, the bolt rest position locking means 116, the torsion bar bolt lock 54, an optional triggering solenoid (not illustrated) and a synchronization cam 11. The drive assembly in addition provides support for an external hydraulic motor 118 and an overriding clutch 120 and gearing 122.

In one specific embodiment of the present invention the bolt 9, which is basically cylindrical in shape, has sixteen locking lugs 124 projecting radially near the forward end of the bolt and a cam follower pin 22 projecting radially near the back end of the bolt. Internally, the bolt contains a pair of grooves 126 engaging torque pins 53 which provide the torque required to lock the bolt into the barrel when the bolt reaches its forward position.

The bolt nose contains a spark igniter (not illustrated), a precombustion chamber 128, and a chamber breech seal 130.

A ball latch mechanism 12 is incorporated in the rear end of the bolt to lock the bolt to the housing during the rest period.

The main cam 6 is an internal cylindrical type with two grooves 132 and 134 which trace bi-directional spiral paths similar to a Yankee screwdriver. The main cam 6 permits the cam follower 22 to rest at each end of its travels until urged back into the grooves 132, 134 by external means. The rear end of the cam 6 has a simple 360° annular groove 137 into which the grooves 132, 134 blend. At the forward end one cam groove 134 expels the follower 22 into a cavity in the drive assembly housing 16 and the other groove 132 accepts the follower 22 when the follower 22 is forced into the groove 132 by a ramp on the control cam for retraction of the bolt.

In one particular embodiment of the present invention the cam 6 is initially driven constantly by the hydraulic motor 118 through the gear train at 3 times gun firing rate, i.e. when the gun is firing at 1000 rounds per minute, the main cam is rotating initially at 3000 rpm. This speed provides approximately an 11 millisecond bolt extension time, 22 millisecond forward dwell, 14 millisecond bolt retraction time after firing, and a 13 millisecond rear dwell time for projectile loading while the gun is firing.

The cam 6 provides a three-fold purpose in the operation of the gun.

First, since the bolt is driven forward by hydraulic pressure in the drive assembly housing, the cam provides no power during the first half of the stroke. Then during the last half of the forward stroke, the cam decelerates the bolt to near zero velocity (as will be described in greater detail below) and converts the energy absorbed by the bolt into rotational energy stored in the cam and other rotating gun mechanisms.

Second, during the return stroke this energy is returned to the bolt (less losses). If there were no losses, the bolt would be returned to its starting position and all the energy expended by the hydraulic system would be recovered. Since there are losses, the losses are made up by the external power source (gas operated piston 66) as will also be described in greater detail below.

The third function of the main cam 6 is to synchronize the bolt operation with the other mechanisms of the gun.

The control cam 27 revolves about the bolt 9 just forward of the main cam 6 and is driven by a gear 136 on the jackshaft 114 at an average speed equal to the gun firing rate. Thus, the control cam 27 operates at a submultiple of the speed of the main cam 6 and rotates in the opposite direction. A small ramp on the rear face of the control cam 27 engages the bolt cam follower 22 at the proper time to urge the cam follower 22 into the return path 132 of the main cam 6.

A pin 29 projects radially from the control cam 27 and serves several purposes. The pin 29 locks the propellant valve 36 in its open position for the time required to fill the combustion chamber 41 with propellant. The pin 29 engages the disable cam 75 in the event a misfire occurs and the cam 75 is not retracted by the piston rod 70. The pin 29 operates the valve 142 controlling the hydraulic mechanism 110 driving the projectile loading hammer 112.

If a misfire occurs, the pin 29 engages the misfire cam 75 and pulls the control cam 27 forward. This disengages the gear 144 on the control cam 27 from the jackshaft pinion 136 and stops the rotation of the control cam. The inertia of the control cam forces a locking taper 146 on the exterior surface of the control cam into engagement with a matching taper 148 in a lock ring 30 attached to the barrel extension. This locks the control cam 27 in its full forward position. The forward motion of the control cam 27 can also be used to open an optional water purge valve (not illustrated) and to force the propellant loading valve 36 forward far enough to provide an exit passageway for the propellant and water

into the gun chamber in the manner illustrated and described in FIGS. 26, 27 and 28 of the above referred to pending patent application Ser. No. 616,822.

The gun module **100**, in a specific embodiment of the present invention, is triggered by an electrical signal to a solenoid (not illustrated in the drawings) connected to a lock plunger **17**.

Since the main cam **6** operates at a multiple of gun speed, a locking or timing cam **11** operating at gun speed is used to prevent the lock plunger **17** from retracting until the main cam **6** is in the proper position with respect to the control cam **27** position. Retraction of the lock plunger **17** allows the ball latch **12** to release the bolt **19**, and hydraulic pressure on the bolt diameter forces the bolt forward.

The drive mechanism **16** utilizes the hydraulic motor **118** to drive all the rotary motions in the gun module **100**.

The motor **118** drives through an overriding clutch **120** and a small gear box **122** directly into the jackshaft **114**. The jackshaft **114**, operating at a multiple of gun speed, in turn is geared to the main cam **6** through an idler gear **150** and drives the control cam **27** at its forward end directly at gun speed. In addition, the locking or timing cam **11** is operated by the jackshaft **114** through the same reduction as the reduction to the control cam **27**.

As indicated above, the average speed of the main cam throughout a cycle is a given rpm, such as, for example, 3000 rpm. However, in order to store the energy transferred from the bolt **9** during the deceleration of the bolt, the main cam **6** speeds up. In order to prevent the hydraulic motor **118** from dissipating this energy as heat in its constant speed hydraulic control, an overriding clutch **120** is used. Thus, the only time power is being absorbed from the hydraulic motor **118** is when the main cam **6** slows down during the return stroke of the bolt to less than its initial speed of 3000 rpm. The peak power required from the hydraulic motor is only required for a few milliseconds during bolt retraction in a gun cycle. At all other times during the cycle the motor operates at considerably less than the peak power to overcome friction and windage losses in the rotating members.

The projectiles **151** are rotating about the gun module **100** and are held in a circular chain or belt containing the projectile containers. To drive this system a harmonic gear train is used. The exterior surface of the main cam **6** provides a cammed surface for driving a flexible inner gear (called the flexspline **7**) of the harmonic drive gear train through a ball drive **8**. The mating internal gear **23** is located in the drive assembly housing **16**. A take off pinion **3** on shaft **152** engages the output gear **23** of the flexspline and drives the projectile retainer mechanism (not illustrated) through projectile drive gear train pinion **48**.

The projectile feed system in each gun module **100** comprises a hammer **112** which forces the projectile **151** out of the conveyor and into the barrel extension **26** through a slot **57**. The hammer **112** is controlled by a piston **110** in a cylinder contained in a barrel extension **26**. The cylinder is designed to apply system hydraulic pressure to the rod side of the piston **110** at all times, thus providing the retraction force required when the head side is connected to return. When it is desired to force a projectile **151** into the module, the spool of a three-way valve **142** is moved to admit fluid pressure to the head side of the piston **110**. The areas of the two sides are arranged to provide the extension force required. The valve spool **142** in turn is controlled by the cam pin **29** in the control cam **27** which moves the valve spool at the proper time in the firing cycle.

FIG. **3** is a schematic of the external hydraulic system used to supply hydraulic power to each gun module **100**.

The muzzle switch actuator **156** used to replenish the hydraulic power required to drive the bolt **9** and the transfer piston **4** used to pressurize the gun module **100** are shown schematically in FIG. **3** although both these mechanisms are physically located in the gun module **100**.

System hydraulic pressure is supplied to the gun system accumulator **158** through a check valve **160** and from the accumulator **158** through a conduit **161** to the inlet of a sequence valve **162** and an electrically operated selector valve **164**. When system pressure is applied to the gun system all of these valves are pressurized as well as the hydraulic motor **118** which drives the rotating members in the gun module **100** at a constant speed (subject to accelerating forces supplies by forward movements of the bolt **9** as described above). In addition, pressurization of the selector valve **164** forces the spool **166** of the sequence valve **162** to the right closing the inlet port **168** and, thus blocking system pressure from the gun transfer piston **4** and the hydraulic fluid chamber **64** of the muzzle switch actuator **156**. The pressure in these chambers is reduced to return system pressure since they are always connected to return through a restrictor check **170**.

In operation, and referring to FIGS. **1** and **3**, when the gun module **100** is placed in the "ready" condition, the hydraulic motor **118** is running and driving the main cam **6** and the control cam **27** and the timing cam **11** at their initial speeds (3000 rpm and 600 rpm respectively in one specific embodiment of the present invention), and the hydraulic motor **118** is also rotating the projectile feed system around the gun module and is driving the projectile supply system (both not illustrated) through the harmonic drive gearing.

The transfer piston **4** is at the left (as viewed in FIGS. **1** and **3**) end of its travel, the bolt **9** is locked in the fully retracted position shown, the muzzle switch piston **66** is at the right end of its travel, and the chamber **64** is filled with hydraulic fluid. The sequence valve slide **166** is at the right (as viewed in FIG. **3**) end of its travel and has closed off system hydraulic pressure to the gun module **100** as described above; and the accumulator **158** is pressurized to system pressure.

When the firing trigger switch and a second switch (not illustrated) on the timing cam **11** are closed, the selector valve **164** on the sequence valve **162** moves the sequence valve slide **166** to the left (as viewed in FIG. **3**) to open the passageway from the inlet port **168** to the outlet port **171** connected to the hydraulic inlet port **1** of the gun.

The hydraulic pressure inlet port **1** is now pressurized, and this pressurizes the interior of the drive housing **16** by means of the hydraulic pressure applied to transfer piston **4**. This tends to move the transfer piston **4** to the right (as viewed in FIG. **1**), and the pressure is transmitted within the barrel extension **26** as far as the plug **49**.

Pressurization of the drive housing **16** produces a load on the lock plunger **17** tending to force the lock plunger **17** to the right against a spring (not shown). The lock plunger **17** is prevented from moving by the

timing cam 11 until the control cam 27 is in the proper angular position for the bolt to start its forward motion. When the lock plunger does move to the right, the lock piston moves to the right to let the balls 12 drop into the groove 116, and this releases the ball lock on the bolt so that the bolt can be moved forward by the hydraulic pressure.

The pressurization of the drive housing 16 provides a force on the bolt 9 tending to force the bolt to the left, but it is prevented from moving by the ball lock mechanism which locks the bolt to the support 19. As noted above, the lock piston 10 is held at the left end of its stroke by the plunger 17 against the load of a spring. A series of balls 12 located in radial holes in the bolt 9 surround the lock piston and are held outward far enough to project from the outside diameter of the bolt. These lock the bolt to the support 19. As soon as the timing cam 11 releases the plunger 17, the plunger moves to the right and the locking piston follows. The locking balls 12 drop into the groove 116 in the piston and now are below the outside diameter suface of the bolt 9. This frees the bolt from the support.

Hydraulic pressure now forces the bolt to the left, and the bolt follower 22 is forced into the forward cam groove 134 of the main cam 6.

Hydraulic fluid now flows into the hydraulic pressure inlet port 1 and into the chamber on the rod side of the transfer piston 4. The transfer piston now moves to the right forcing the fluid out of the chamber on its head side, through the passageway 172 shown in the end cap 13 into the drive housing 16.

The displacement of the transfer piston 4 is equal to that of the bolt plus any leakage of fluid from the housing 16.

Makeup of any fluid losses is done with the valve 5. If leakage has occurred, the piston 4 will be displaced farther than normal. Toward the end of its stroke the stem of the valve 5 will contact the closure 13 and further motion of the piston 4 will open the valve 5. Hydraulic fluid can now flow from the port 1 through the valve port 2 into the bore on the head side of the piston 4. The piston 4 is now forced to the left until the valve closes and shuts off the flow.

As the bolt 9 accelerates to the left (as viewed in FIG. 1), the angle of the cam forward groove 134 is kept at such a value that no contact with the bolt cam follower 22 is made. The main cam 6 continues to rotate at its initial angular velocity of 3000 rpm. At approximately 3.7 inches of the bolt's total travel of 7.3 inches (in one specific embodiment of the present invention) sufficient kinetic energy has been transferred from the hydraulic system to the bolt 9 to overcome the losses during the remainder of the cycle. The angular inclination of the cam groove 134 is now steepened. This applies a retarding force on the cam follower 22 and the bolt which slows the bolt to near zero velocity just before bolt locking occurs. The kinetic energy transferred from the bolt to the main cam 6 now increases the angular velocity of the main cam and the angular velocity of all other rotating members geared to the main cam 6. The hydraulic motor 118 continues to operate at its initial speed since the overriding clutch 120 in series with the drive permits the driven members to overspeed.

The locking lugs 124 at the head end of the bolt are located in mating grooves 106 in the barrel extension 26. These grooves are also shown in FIG. 5.

Just before the bolt 9 started its forward motion a projectile 151 was forced from the feed belt through the passageway 57 into the receiver bore 47. The entry of the projectile 151 forces the projectile sensor 55 upward when the projectile 151 strikes the lug 58.

As the bolt starts its forward stroke the pin cam locking rod 56 can now follow under the influence of the hydraulic pressure in the housing 16 since it is no longer locked in place by projectile sensor 55. In addition pin cam actuating rod 50 which was held in its rearward position by the bolt locking lug can now move forward under the same hydraulic pressure load. This movement forces pin cam 51 forward until pin 50 strikes its stop. The forward motion of pin cam 51 extends control cam pin 29 at the proper time so that it may perform its functions listed above.

The projectile sensor has a helical rack 174 on one side which engages helical gear teeth 176 on the cam 33. Upward motion of the projectile sensor causes rotation of the cam 33 and forces sear hook 32 into the pathway of a locking lug 124 on the bolt 9. Thus, the sear hook 32 is forced to the left (as viewed in FIG. 1) when the lug 124 strikes the sear hook 32. The sear hook, in turn, is attached to the propellant valve stem 34 and forces the propellant valve 36 to the left when the lug 124 strikes the sear hook 32. Leftward movement of propellant valve stem 34 and propellant valve 36 opens a passageway from the propellant inlet port 35 to combustion chamber inlet port 42.

When the bolt 9 returns, the projectile sensor 55 is forced downward by torsion bar spring 108 through arm 109 onto the rod 56 after the bolt 9 passes the projectile sensor 55. The locking lug 124 on the bolt contacts the pin 50 near the end of its stroke forcing the pin 50 and the pin cam 51 and the rod 56 to the right (as viewed in FIG. 1) returning them to their original positions. When the rod 56 is fully retracted, the projectile sensor 55 drops to its initial position as illustrated in FIG. 5 and locks rod 56 and thus pin cam 51 in their original positions.

Since a pin 29 is located at the control cam 27, the pin 29 is rotating about the bolt 9 and can be extended radially at the proper time by the cam surface on the pin cam 51 which is not rotating. Thus, the functions of the pin 29 and the module disable and propellant valve timing operation are controlled by the motion of the pin cam 51. The pin 29 is held radially inward against the pin cam 51 by a cantilever spring 180 shown as a round cross section through the pin 29 in FIG. 1.

As indicated above, the bolt 9 forces the propellant valve 36 to the left when a locking lug 124 strikes the sear hook 32.

As the projectile 151 which forced the sensor 55 upward moves out from under the lug 58, the lug passes onto the surface of the bolt, and this holds the sensor 55 in the retracted position. The sear hook 32 therefore remains in the position required to engage the bolt 9. As the propellant valve 36 moves toward the left, it also forces the blocking slide 39 to the left. This forces hydraulic fluid in the chamber 182 to the left of the blocking slide into a hydraulic spring chamber in the gun barrel 43 and provides a high return force required to close the propellant valve 36 at the end of the propellant filling portion of the cycle.

During its entire stroke to the left, the bolt 9 has a high torque applied in a clockwise sense when viewed from the right end of the gun module 100 in FIG. 1. This torque is provided by the torsion bar 54 through two torque pins 53 which ride in the grooves 126 cut in the inside diameter of the bolt. These pins, in turn, are

guided in the bore and retained by the torque head 52. When the bolt reaches the end of its stroke, the locking lugs 124 on the bolt are forced out of the guide grooves 107 in the barrel 43, which grooves match the grooves 106 in the barrel extension 26, and the locking lugs 124 pass into a relief groove 45 in the barrel 43.

At the same time the cam follower 22 in the bolt is expelled from the forward groove 134 in the main cam 6 and exits into a groove 186 in the housing 16.

The bolt 9 is now free to rotate in a clockwise direction (as viewed from the right end of the gun module 100 in FIG. 1) under the influence of the torsion bar 54. The groove 186 in the housing 16 is limited in length and stops the bolt rotation at 11.25° in one specific embodiment of the present invention. The locking lugs 124 on the bolt are now behind the locking lugs 102 in the barrel 43, and the bolt is prevented from being forced to the right (backward as viewed in FIG. 1 by the gas pressure which is generated in the barrel 43 when firing occurs.

As the bolt 9 and the propellant valve 36 reach their forward position, the pin 29 is forced outward by the pin cam 51, and the pin 29 passes behind an arc cam 28 which is attached to the propellant valve shaft 34.

The propellant valve 36, which is no longer retained by the sear hook 32 after the bolt has been rotated to lock, is now prevented from closing under the influence of the hydraulic spring force acting on the blocking slide 39. The pin 29 holds the valve 36 open for that portion of the cycle required for propellant filling. The projectile 151 which has been positioned to the left of the port 42 by the bolt 9 is now forced further to the left in the gun chamber 41 by the propellant entering the combustion chamber through the ports 35 and 42. Propellant flows through the port 35, past the propellant valve 36, into the gun chamber 41 through the port 42.

When the projectile 151 reaches the forcing cone (not illustrated) in the gun barrel, it stops and the propellant flow stops.

At this time the pin 29 in the control cam 27 has passed from behind the arc cam 28; and the propellant valve 36 and the blocking slide 39 move to the right and close the port 42.

The gun chamber is now sealed by the bolt and the blocking slide by high pressure seals on these members. The blocking slide moves in the sleeve 37 which retains the sealing members in a mating bore in the barrel. The high pressure gas in the chamber 41, after firing, forces elastomeric seals at the ends of the sleeve 37 outward against a pair of metallic rings 190. These rings 190 have matching 45° taper surfaces at their interface, and thus one ring is forced outward and the other inward under the influence of the gas pressure. The rings being forced inward seal the outside diameter of the blocking slide while those being forced outward seal the bore for the sleeve in the barrel. Should the seals on the right end of the sleeve leak, the space between the propellant valve head 36 and the blocking slide 39 will become pressurized. Since the propellant valve is prevented from moving to the right by a shoulder on the valve head which mates with a counterbore in the barrel extension 26, the blocking slide 39, in the event of leakage of gas, is forced to the left against the hydraulic spring pressure, and the blocking slide opens a vent port 40 to the space between the two members which was sealed by the conical seal on the propellant head. This movement allows leakage gas to escape without building up high gas pressure on the propellant valve head 36. A leak through the seal at the left end of the sleeve passes out through the vent port 38.

Isolation of the main propellant supply from the firing chamber 41 in the gun is accomplished by the mechanism described above. As the valve 36 moves to the right to close, the valve 36 forces the propellant behind the valve head back into the barrel extension 26. The barrel extension 26 is thermally isolated from the gun barrel 43 by insulation 44 and 46 between the members.

The locking lugs 102 on the barrel 43 are located in a cylindrical extension of the barrel, and this extension fits into a mating counterbore in the barrel extension 26 as illustrated. A small air gap (not shown in the drawings) is maintained between these members at this point and serves as insulation. The only direct connection between the two members is through three close fitting pins (as described above) which lock the members together.

Ignition of the liquid propellant charge is accomplished by electric spark ignition in the precombustion chamber 128 located in the bolt head. This ignites the propellant in the gun chamber 41, and the pressure in the gun chamber 41 forces the projectile 151 past the forcing cone and through the barrel 43.

After burning has been completed, further travel of the projectile expands the gases in the gun chamber 41 and the pressure decreases. When the pressure has been decreased to approximately 20,000 psi (in one specific embodiment of the present invention) a port 14 (See FIG. 4.) is passed by the projectile 151 and opens the chamber 74 in the muzzle switch to the right of the piston 71 to the pressure in the gun barrel 43. The pressure is prevented from escaping past the piston rod 70 and piston head 71 by high pressure seals 73 and 72 respectively. The force generated by the gas pressure forces the piston 71 to the left (as viewed in FIG. 4), and the piston 66 in the chamber 64 which is filled with hydraulic fluid is also forced to the left.

This motion of the pistons 71 and 66 forces the fluid in the chamber 64 through the passageway 192 in the rod 70 and forces piston 63 to the left until stopped by plug 61. The high pressure fluid passes from this passageway 192 through a cavity 194 in the barrel extension (See FIG. 3.) where the fluid exits the gun module 100.

The fluid closes the restrictor check valve 170 and passes through a second check valve 196 in the free-flow direction into the gun system accumulator 158. The pressure also drives the sequence valve spool 166 to the right, if the selector valve 164 (which was reversed during the propellant fill portion of the cycle by a switch on the timing cam) has not completed the shutoff stroke of the sequence valve spool 166.

The movement of the sequence valve spool 166 shuts off the pressure port 168 from the gun port 1.

The gas piston 71 moves to the left until it strikes the stop 68 retained by the ring 67.

Any gas pressure escaping past the seal rings 72 is vented through the port 69.

When the piston 71 bottoms, the hydraulic pressure in passageway 192 and chamber 64 decays to return pressure since the passageway in the rod 70 is connected to the return system through a small orifice in the now closed restrictor check 170. The decay in pressure allows the restrictor check 170 to open which increases the size of the orifice. The piston 63 can now move to the right under the influence of the spring 62 forcing its displaced oil out the restrictor check 170.

The gun incorporates a mechanism which disables the gun module **100** in case a misfire occurs. See FIG. **6**. This is accomplished by placing a cammed surface **75** in the path of the pin **29** in the control cam **27**. If the gun fires, this cam **75** is retracted out of the path of the pin **29** by the piston **71** through the rod **70**. The rod **70** extends into the cavity occupied by the control cam **27** and has the disable cam surface **75** attached to its end.

If the gun misfires and the cammed surface **75** is not retracted, the pin **29** strikes the surface **75** forcing the pin **29** and the control **27** to the left, as viewed in FIG. **1**. This motion disengages the gear on the control cam **27** from the driving pinion **136** on the jackshaft **114** and stops the rotation of the control **27**.

The inertia of the control cam **27** carries the control cam to the left, as viewed in FIG. **1**, until the taper **146** on the cam nose locks into the mating taper **148** of the lock ring **30** which now prevents any further motion of the control cam **27**.

The bolt **9** which normally would be unlocked by the rotation of control cam **27** remains locked.

The leftward motion of the control cam **27** also forces the pin **31** to the left which, in turn, forces the propellant valve **36** to the left far enough to connect the port **42** to the intersection between the valve head **36** and the blocking slide **39**. In this event a water valve (not) illustrated) is also opened by the motion of the control cam **27** to admit high pressure water to the gun chamber **41** at the base of the projectile **151**. The water then forces the liquid propellant and water out the vent port **38**.

Assuming that a normal firing takes place and the gun module **100** is not disabled, the bolt **9** is unlocked by the rotation of the control cam **27**. A ramp on the control cam **27** engages the bolt cam follower pin **22** and rotates the bolt cam follower pin **22** until the locking lugs **124** in the bolt head are disengaged from the mating lugs **102** in the barrel **43**.

Since the residual pressure in the barrel **43** is still high and the return groove **132** in the main cam **6** is in line with the follower **22**, the bolt **9** is accelerated to the right (as viewed in FIG. **1**) and the follower **22** enters the return cam groove **132**.

The inclination of the cam groove **132** is such that the rotational energy in the main cam **6** is now translated into an accelerating force on the bolt **9**. Thus, initially, both the residual pressure in the gun chamber **41** acting on the bolt area and the force of the main cam **6** accelerate the bolt **9** to the right. After approximately 0.6 inches of bolt travel the residual pressure has decreased to zero and no longer provides force. The main cam **6** now provides the only accelerating force.

The bolt motion displaces hydraulic fluid from the interior of the drive chamber **16** into the bore **204** in which the transfer piston **4** slides. The piston **4** moves to the left (as viewed in FIG. **1**) displacing fluid out of the port **1**.

Referring to FIG. **3**, it will be noted that this fluid cannot pass through the sequence valve **162** since the sequence valve **162** is still closed. The fluid must pass through the check valve **206**. The fluid cannot pass through the check valve **196** since the check valve **196** is held closed by the system pressure. Check valve **170** is closed by the high flow rate of the fluid exiting port **1**.

The fluid is forced into the chamber **64** through the passageway **192** in the rod **70**. Since during the first 0.6 inch of bolt travel the residual pressure in the gun barrel **43** and thus in the chamber **74** is still high, the fluid entering the chamber **64** cannot force the piston **66** to the right. Therefore, the oil displaces the piston **63** to the left against the force of the spring **62**. When the piston **63** has reached the end of its stroke, the residual pressure has decayed to a low value, and further displacement of the bolt **9** will result in forcing the piston **66** to the right.

The bolt **9** proceeds to the right accelerated by the main cam **6**. When the angular velocity of the main cam **6** has been reduced to its initial value, the hydraulic motor **118** is again engaged through the overriding clutch **120** and adds its power to return the bolt. The cam angle of the "return" groove **132** in the main cam **6** is changed at this time so that energy is no longer transferred to the bolt **9** from the main cam **6**. The bolt now proceeds to the end of its travel opposed by the force generated by the pressure drop of the exiting fluid and by friction forces and reaches the rest groove **136** in the main cam at near zero linear velocity.

As the bolt **9** is retracting, piston **66** is moving toward the right; and as the bolt **9** nears the end of its stroke and its velocity is reduced, the pressure in the chamber **64** (which reflects the pressure drop of the returning oil from the transfer piston **4**) is also reduced. Thus, near the end of the stroke, the pressure in the chamber **64** is low enough that the spring **62** can force the piston **63** to the right to the end of its travel. Therefore, when the bolt reaches the rest groove **137**, all the fluid which was displaced is once again restored to the chamber **64** (with the exception of that which was lost to the return system through the restrictor check **170**).

The makeup fluid required is replenished as soon as the sequence valve **162** opens the pressure port **168** to the gun module. The slide **166** is moved to the left at the end of the bolt return stroke by reversal of the selector valve **164** admitting pressure to the gun port **1**.

Fluid can now flow into the chamber **64** from system pressure.

The piston **63** is forced to the left again to await the next firing cycle.

If the trigger has been released during the cycle, the selector valve **164** on the sequence valve **162** is deenergized by the timing cam **11** at the proper point in the cycle. The spool **166** in the valve **162** is forced to the right closing off pressure to the gun module **100**.

The pressure in the system decreases to return pressure, and the plunger **17** is now urged to the left by a spring. The timing cam **11** prevents the plunger from moving until the bolt has reached its fully retracted position. The plunger then moves to the left forcing the locking piston **10** to the left and extending the lock balls **12** behind the shoulder of the support **19**, thus locking the bolt **9**.

As indicated above, the projectile feed mechanism is geared to the main cam **6** and thus is driven by the hydraulic motor **118**. The gearing is arranged in a manner known as a harmonic drive. This type of drive consists of a flexible, external gear which engages the teeth of a fixed internal gear when the flexible external gear is deflected by an elliptical cam on its interior surface. Thus, as the elliptical cam rotates, the two points at which the flexible member, known as a spline, engage the internal gear rotate with the cam. If the spline now has two teeth less than the fixed internal gear, the spline will advance two teeth for each revolution of the cam. A third gear attached to the spline can now be used to drive the external mechanism which in this case is the projectile feed.

The elliptical cam is machined as three ball races at the right end of the main cam 6. See FIG. 1. The balls 8 are held in these elliptical grooves by a suitable ball separator member and by the inside diameter of the flexible spline 7. The spline is shown in engagement with the fixed internal gear 20 which also provides a support for the bearing 21 which in turn supports the main cam.

Thus, as the main cam 6 turns, the points of engagement of the spline in the fixed internal gear rotate about the main cam 6. As explained above, the spline now rotates at a gear ratio equal to one-half the number of teeth in the internal gear.

The output gear 23 is an integral part of the flexible spline and rides on a bearing surface at the left end of the main cam 6.

A pinion gear 3 is driven by the gear 23 and drives one of the gears 48 in the feed mechanism gear train through a shaft supported by the barrel extension 26.

The gun module 100 of the present invention thus provides a number of features including:

a. A method to drive the bolt directly with hydraulic pressure and still retain the Yankee screwdriver type main cam to control the bolt;
b. A timing cam for synchronizing the bolt release with the position of the control and thus the forward groove of the main cam;
c. A torsion bar, bolt-locking system;
d. A propellant valve opened by the bolt motion which provides isolation of the propellant supply from the gun chamber during firing and which also provides the necessary rapid opening of the propellant valve;
e. A projectile sensing device which prevents propellant from being pumped into the gun chamber and which also prevents the gun module from being disabled if a projectile is not loaded;
f. A piston and rod assembly that senses that firing has occurred and that uses the gas pressure generated to pump high pressure hydraulic fluid back into the supply system to make up the energy expended during the bolt forward stroke. This same piston and rod assembly operates the disable cam;
g. A ball locking device to lock the bolt in its most rearward or bolt open position when the gun is not firing; and
h. A harmonic drive gear mechanism to provide power to the projectile feed system.

While we have illustrated and described the preferred embodiments of our invention, it is to be understood that these are capable of variation and modification, and we therefore do not wish to be limited to the precise details set forth, but desire to avail ourselves of such changes and alterations as fall within the purview of the following claims.

We claim:

1. A liquid propellant gun of the kind in which liquid propellant is burned in a combustion chamber to fire a projectile from the gun and comprising,
   a bolt mounted for axial movement between a rearward, projectile loading position and a forward, projectile firing position, and
   drive assembly means for reciprocating the bolt between the rearward and forward positions, said drive assembly means including drive mechanism for driving the gun and an outer case constructed to provide a sealed enclosure about the bolt and the drive mechanism and fluid pressurizing means for conducting high pressure hydraulic fluid to the interior of the case and directly against the back surfaces of the bolt to drive the bolt forward by the forces produced by the high pressure fluid action on the rear surfaces of the bolt within the outer case and to provide lubrication for all internal moving parts of the drive mechanism within the outer case.

2. The invention defined in claim 1 including a propellant injection control valve for controlling the injection of liquid propellant into the combustion chamber and wherein the valve is operatively associated with the bolt so that the valve is opened by forward movement of the bolt.

3. The invention defined in claim 1 wherein the fluid pressurizing means include a transfer piston for transferring pressure from a source of high pressure fluid independent of the gun to the interior of said case.

4. The invention defined in claim 3 including sequence valve means operatively associated with said transfer piston for controlling the application of high pressure from said source of high pressure fluid to the transfer piston.

5. The invention defined in claim 1 including liquid propellant injection means for injecting a liquid propellant into the combustion chamber.

6. The invention defined in claim 5 including projectile sensor means for sensing when a projectile has entered the gun and operatively associated with the propellant valve for opening the propellant valve only when a projectile has entered the gun.

7. The invention defined in claim 5 wherein the propellant valve is operatively associated with the bolt so that forward movement of the bolt opens the propellant valve.

8. A liquid propellant gun of the kind in which liquid propellant is burned in a combustion chamber to fire a projectile from the gun and comprising,
   a bolt mounted for axial movement between a rearward, projectile loading position and a forward, projectile firing position, and
   drive assembly means for reciprocating the bolt between the rearward and forward positions, said drive assembly means including an outer case and fluid pressurizing means for conducting high pressure fluid to the interior of the case and directly against the back surfaces of the bolt to drive the bolt forward by the forces produced by the high pressure fluid acting on the rear surfaces of the bolt within the outer case and including an accumulator operatively associated with the sequence valve for storing high pressure fluid at the pressure of said source of high pressure fluid after the sequence valve has closed off the source of said high pressure fluid from the accumulator and the liquid propellant gun.

9. The invention defined in claim 8 including gas operated pumping means powered by the gases produced by the firing of the projectile and operatively associated with the sequence valve means and the accumulator for making up during the rearward movement of the bolt energy losses from said fluid pressure incurred during the forward movement of the bolt and the loading of the projectile during each cycle of cperation of the gun.

10. A liquid propellant gun of the kind in which liquid propellant is burned in a combustion chamber to fire a projectile from the gun and comprising,

a bolt mounted for axial movement between a rearward, projectile loading position and a forward, projectile firing position, and

drive assembly means for reciprocating the bolt between the rearward and forward positions, said drive assembly means including an outer case and fluid pressurizing means for conducting high pressure fluid to the interior of the case and directly against the back surfaces of the bolt to drive the bolt forward by the forces produced by the high pressure fluid acting on the rear surface of the bolt within the outer case and wherein the drive assembly means include a main cam mounted for rotation within the outer case and operatively associated with the bolt during the forward and rearward reciprocation of the bolt.

11. The invention defined in claim 10 wherein the bolt includes a cam follower engaged with the main cam, the main cam extends parallel to the bolt and has a forward cam groove which receives the bolt cam follower during forward motion of the bolt and wherein the forward cam groove has an angular inclination which causes the cam follower to engage a side of the forward cam groove near the end of the forward motion of the bolt both to decelerate the forward motion of the bolt and at the same time to store energy from the decelerating bolt into the main cam and other structure mounted for rotation with the main cam by converting the deceleration of the axial motion of the bolt into acceleration of the rotary motion of the main cam.

12. The invention defined in claim 11 wherein the main cam includes a return groove which receives the bolt cam follower during rearward motion of the bolt and wherein the angular inclination of the return cam groove causes a side of the return cam groove to engage the cam follower to drive the bolt rearward by the rotary motion of the main cam only during the first part of the rearward movement of the bolt.

13. The invention defined in claim 10 including projectile feed mechanism means for feeding projectiles to the gun and gear means connecting the projectile feed means to the main cam for drive from the rotation of the main cam.

14. The invention defined in claim 13 wherein the gear means include harmonic drive gear reduction gearing for driving the projectile feed mechanism at a much slower speed than the speed of rotation of the main cam.

15. The invention defined in claim 13 including a hydraulic motor connected to drive the main cam.

16. The invention defined in claim 15 including an overrunning clutch in the drive connection between the hydraulic motor and the main cam so that the main cam can rotate faster than the speed of rotation of the hydraulic motor during certain parts of a cycle of operation of the gun.

17. The invention defined in claim 10 wherein the barrel has bolt locking lugs and the bolt has mating locking lugs and the bolt is mounted for limited rotation so that the bolt locking lugs engage the barrel locking lugs when the bolt is rotated to a locked position at the forward end of the stroke.

18. The invention defined in claim 17 including a control cam mounted for rotation within the outer case and engagable with the bolt cam follower for rotating the bolt to an unlocked position after firing.

19. The invention defined in claim 18 including cam drive means in the drive assembly means effective to rotate the main cam at a multiple of the speed of rotation of the control cam and including a timing cam operatively associated with the main and the control cam for synchronizing the entry of the bolt cam follower into the forward groove of the main cam.

20. The invention defined in claim 18 including a pin cam operatively associated with the control cam for controlling the injection of propellant into the gun.

21. The invention defined in claim 20 including a propellant inlet valve and wherein the pin cam includes a pin operatively associated with the propellant inlet valve for holding the propellant inlet valve open for the amount of time required to fill the firing chamber of the gun with liquid propellant.

22. A liquid propellant gun of the kind in which liquid propellant is burned in a combustion chamber to fire a projectile from the gun and comprising,

a bolt mounted for axial movement between a rearward, projectile loading position and a forward, projectile firing position, and

drive assembly means for reciprocating the bolt between the rearward and forward positions, said drive assembly means including an outer case and fluid pressurizing means for conducting high pressure fluid to the interior of the case and directly against the back surfaces of the bolt to drive the bolt forward by the forces produced by the high pressure fluid acting on the rear surfaces of the bolt within the outer case and including gas operated motor means powered by the gases produced upon firing of a projectile from the gun and including a movable piston powered by said gases to provide a plurality of functions.

23. The invention defined in claim 22 wherein the piston pumps hydraulic fluid to make up on the return stroke of the bolt fluid pressure and energy losses incurred during forward movement of the bolt during each cycle of operation of the gun.

24. The invention defined in claim 22 wherein the gun includes an external hydraulic circuit and a control valve for controlling the supply of the fluid pressure to the drive assembly and wherein the piston is operatively associated with the control valve to operate the control valve on each firing cycle of the gun.

25. The invention defined in claim 22 including misfire detection means and wherein the piston operates the misfire detection means to disable the gun module in the event of a misfire.

26. A liquid propellant gun of the kind in which liquid propellant is burned in a combustion chamber to fire a projectile from the gun and comprising,

a bolt mounted for axial movement between a rearward, projectile loading position and a forward, projectile firing position, and

drive assembly means for reciprocating the bolt between the rearward and forward positions, said drive assembly means including an outer case and fluid pressurizing means for conducting high pressure fluid to the interior of the case and directly against the back surfaces of the bolt to drive the bolt forward by the forces produced by the high pressure fluid acting on the rear surfaces of the bolt within the outer case and including a gun barrel having barrel locking lugs, bolt locking lugs on the bolt, and torsion rod bolt locking means for rotating the bolt and bolt locking lugs into locking engagement with the barrel locking lugs at the end of the forward movement of the bolt.

27. A liquid propellant gun of the kind in which liquid propellant is burned in a combustion chamber to fire a projectile from the gun and comprising,

a bolt mounted for axial movement between a rearward, projectile loading position and a forward, projectile firing position and mounted for rotary movement between a locked position and an unlocked position,

a barrel having barrel locking lugs,

bolt locking lugs on the bolt, and

torsion rod bolt locking means for rotating the bolt and the bolt locking lugs into locked engagement with the barrel locking lugs at the end of the forward movement of the bolt.

28. A liquid propellant gun of the kind in which liquid propellant is burned in a combustion chamber to fire a projectile from the gun and comprising,

a bolt mounted for axial movement between a rearward, projectile loading position and a forward, projectile firing position,

liquid propellant injection means for injecting a liquid propellant into the combustion chamber,

said liquid propellant injection means including a propellant control valve and propellant control valve opening means attached to the propellant control valve and mechanically engageable with the bolt at a certain point in the forward travel of the bolt to physically move the propellant control valve to an open position as the bolt travels to its full forward position wherein the bolt is operatively associated with the propellant control valve to open the propellant control valve by the forward movement of the bolt.

29. A liquid propellant gun of the kind in which liquid propellant is burned in a combustion chamber to fire a projectile from the gun and comprising,

a bolt mounted for axial movement between a rearward, projectile loading position and a forward, projectile firing position,

liquid propellant injection means for injecting a liquid propellant into the combustion chamber, said liquid propellant injection means including a propellant control valve and bolt engaging means for moving the control valve to an open position when engaged by the bolt, and

wherein the projectile sensor means are operatively associated with the bolt engaging means for the propellant control valve to open the propellant control valve only when a projectile has actually entered the gun.

30. A liquid propellant gun of the kind in which liquid propellant is burned in a combustion chamber to fire a projectile from the gun and comprising,

a bolt mounted for axial movement between a rearward, projectile loading position and a forward, projectile firing position,

liquid propellant injection means for injecting a liquid propellant into the combustion chamber,

said liquid propellant injection means including a propellant control valve which must be open to inject propellant into the combustion chamber,

projectile sensor means for opening the propellant control valve only when the projectile enters the gun,

an operative connection between the bolt and the propellant control valve effective to open the control valve by the forward movement of the bolt, and

ball lock means for retaining the bolt in a rearward, locked position until the start of a firing cycle.

31. A liquid propellant gun of the kind in which liquid propellant is burned in a combustion chamber to fire a projectile from the gun and comprising,

a bolt mounted for axial movement between a rearward, projectile loading position and a forward, projectile firing position,

drive assembly means for reciprocating the bolt between the rearward and forward positions, said drive assembly means including a main cam mounted for rotation and operatively associated with the bolt during the forward and rearward reciprocation of the bolt,

a drive motor for rotating the main cam,

projectile feed means for feeding projectiles to the gun, and

harmonic drive means including harmonic drive gearing interconnecting the main cam and the projectile feed mechanism for driving the projectile feed mechanism in synchronism with the main cam and effective to drive the projectile feed mechanism from the main cam at a large gear reduction ratio with a minimum of gear mechanism size, said harmonic drive gearing comprising a flexible external gear, a fixed internal gear, and a rotatable elliptical cam engaged with the flexible external gear to cause the points at which the two gears are engaged to rotate with the rotation of the elliptical cam.

32. A liquid propellant gun of the kind in which liquid propellant is burned in a combustion chamber to fire a projectile from the gun and comprising,

a bolt mounted for axial movement between a rearward, projectile loading position and a forward, projectile firing position and having a cam follower,

drive assembly means for reciprocating the bolt between the rearward and forward positions, said drive assembly means including a main cam having forward and return cam grooves operatively associated with the bolt cam follower for providing part of the drive to the bolt during certain parts of a cycle of operation and for receiving driving motion from and for storing energy from the bolt during other parts of a cycle of operation,

a separate control cam for controlling certain events in a cycle of operation of the gun,

drive means operatively associated with the drive cam and the control cam for rotating the drive cam at a multiple of the speed of rotation of the control cam, and

a timing cam operatively associated with the main cam and control cam for synchronizing entry of the bolt cam follower into the groove of the main cam at the proper times in each cycle of operation of the gun.

* * * * *

United States Patent [19]

Elmore et al.

[11] **4,164,889**

[45] **Aug. 21, 1979**

[54] **LIQUID PROPELLANT MODULAR GUN INCORPORATING DUAL CAM OPERATION AND INTERNAL WATER COOLING**

[75] Inventors: **Lester C. Elmore**, Portola Valley, Calif.; **Thomas M. Broxholm, deceased**, late of Palo Alto, Calif., by Anne K. Broxholm, administratrix

[73] Assignee: **Pulsepower Systems, Inc.**, San Carlos, Calif.

[21] Appl. No.: **834,336**

[22] Filed: **Sep. 19, 1977**

Related U.S. Application Data

[62] Division of Ser. No. 616,822, Sep. 25, 1975, Pat. No. 4,062,266.

[51] **Int. Cl.**[2] **F41F 1/04**
[52] **U.S. Cl.** **89/7**; 89/11
[58] **Field of Search** .... 89/7, 11, 1 L

[56] **References Cited**

U.S. PATENT DOCUMENTS

3,800,657 4/1974 Broxholm et al. 89/7

Primary Examiner—David H. Brown
Attorney, Agent, or Firm—Donald C. Feix

[57] **ABSTRACT**

A liquid propellant modular gun has a slim profile and is constructed for wide latitude in gun cluster configuration.

The modular gun has a stationary barrel and is externally driven and cam operated by a drive cam and a control cam.

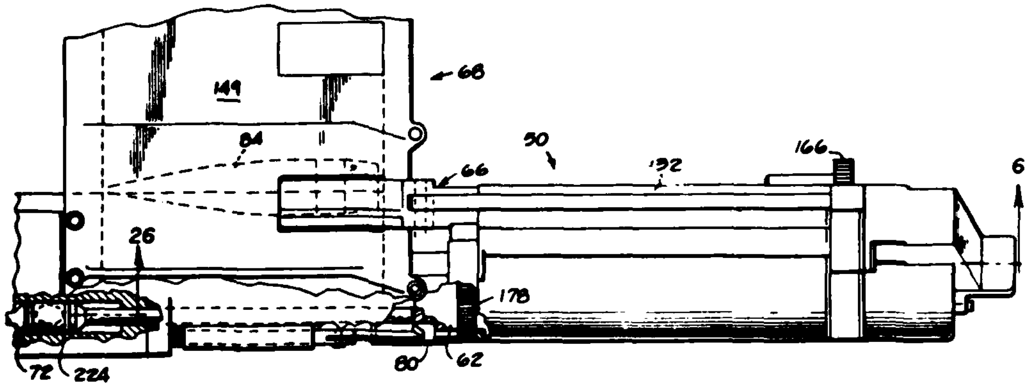
The drive cam has one internal spiral cam track for driving the bolt forward to a projectile firing position and another internal spiral cam track for driving the bolt rearward to a projectile loading position.

The control cam is mounted for rotation at the forward end of the drive cam and controls the injection of liquid propellant into the combustion chamber and an electrical igniter.

A water injection mechanism is also associated with the control cam for injecting a small amount of water into the combustion chamber after the firing of each round to cool the combustion chamber structure by internal water cooling. The water injection mechanism is also effective to purge propellant from the combustion chamber in the event of a misfire.

The bolt is rotated to a locked position at the forward end of its travel where locking lugs on the bolt are engaged with mating lugs on the barrel so that all breach loads caused by chamber pressure are carried through the barrel rather than the receiver. This permits the receiver to be made quite light.

3 Claims, 46 Drawing Figures



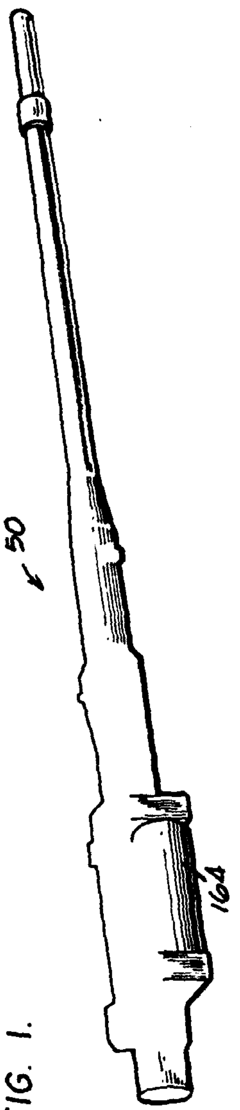


FIG. 1.

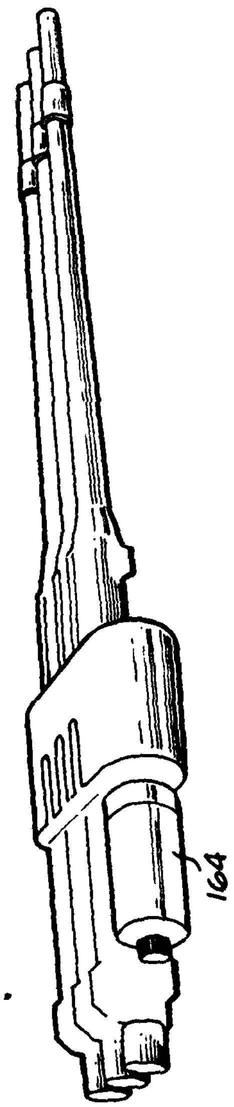


FIG. 2

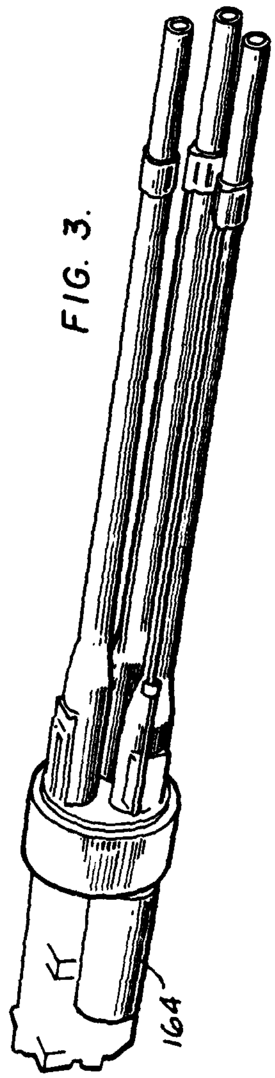
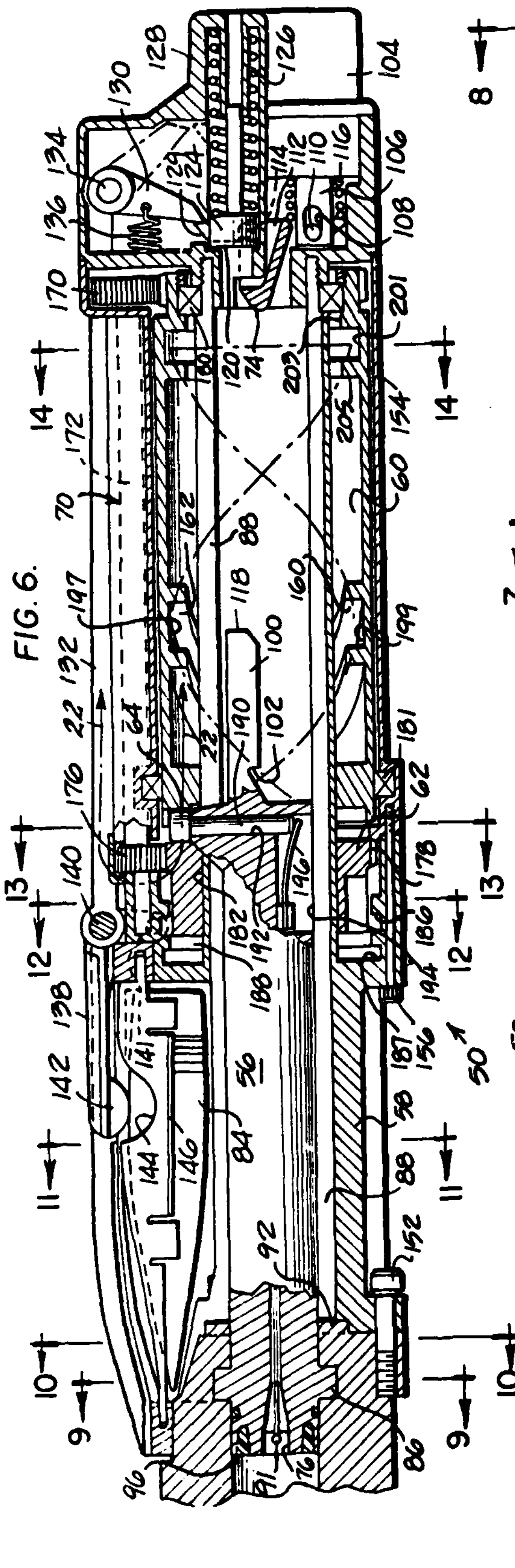


FIG. 3.



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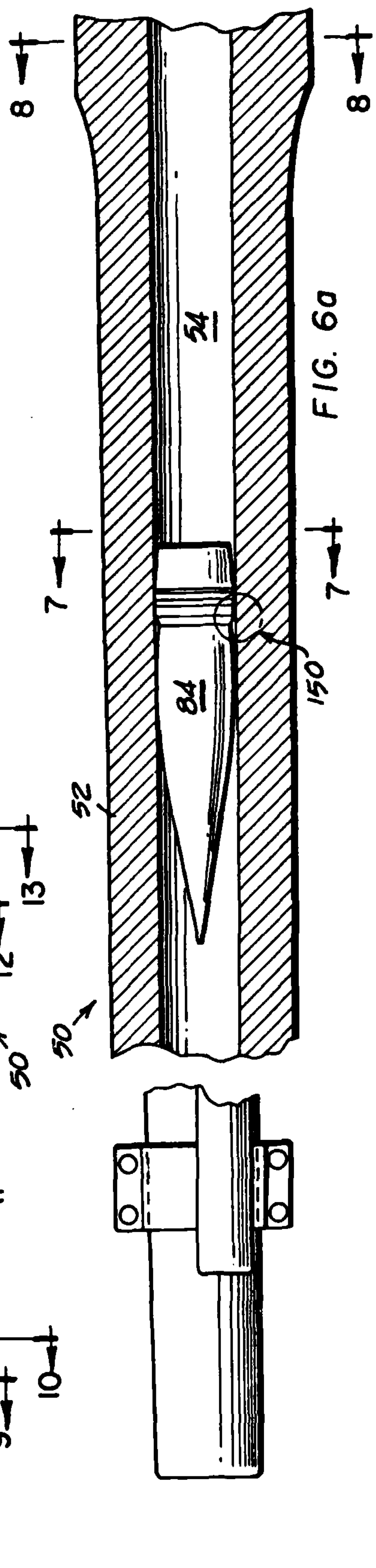

FIG. 6a

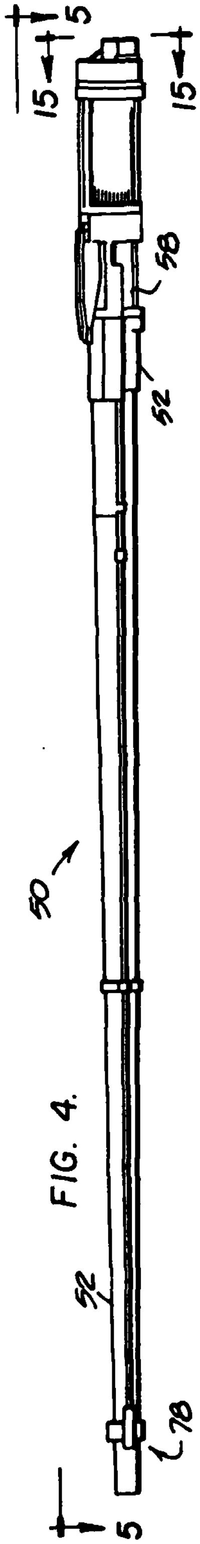

FIG. 4.

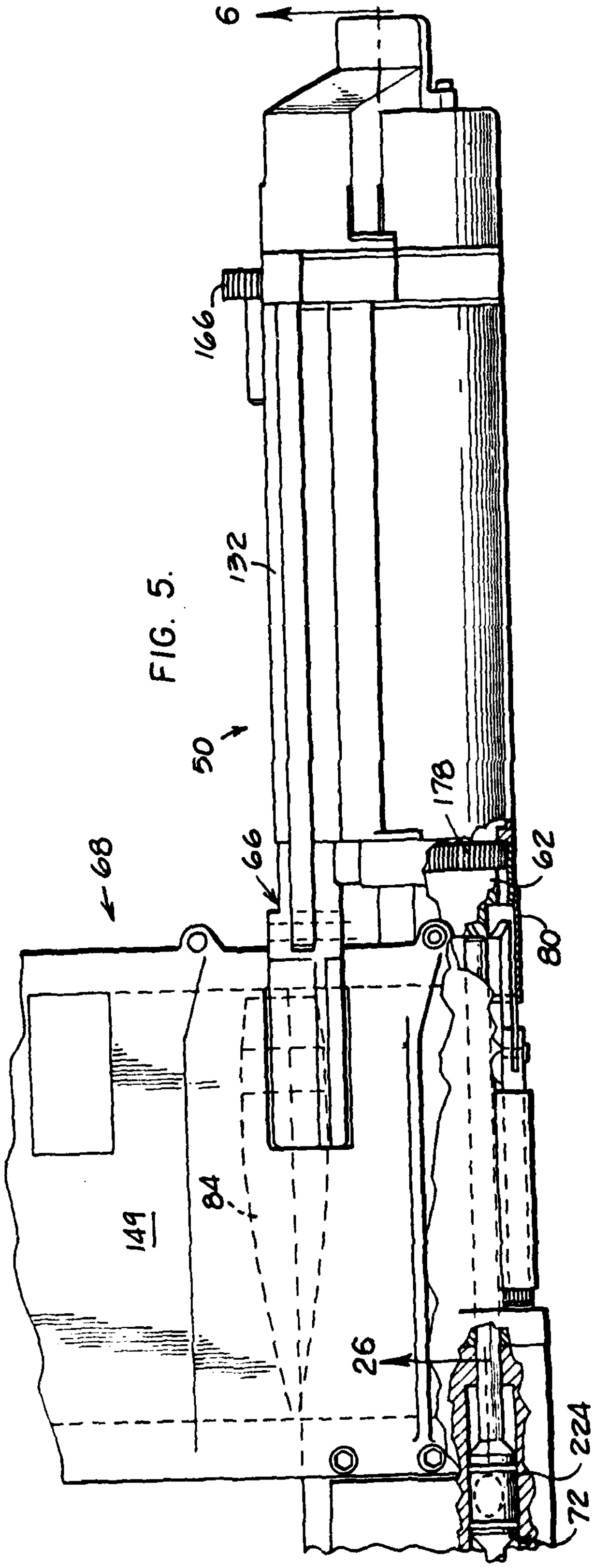

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FIG. 5.

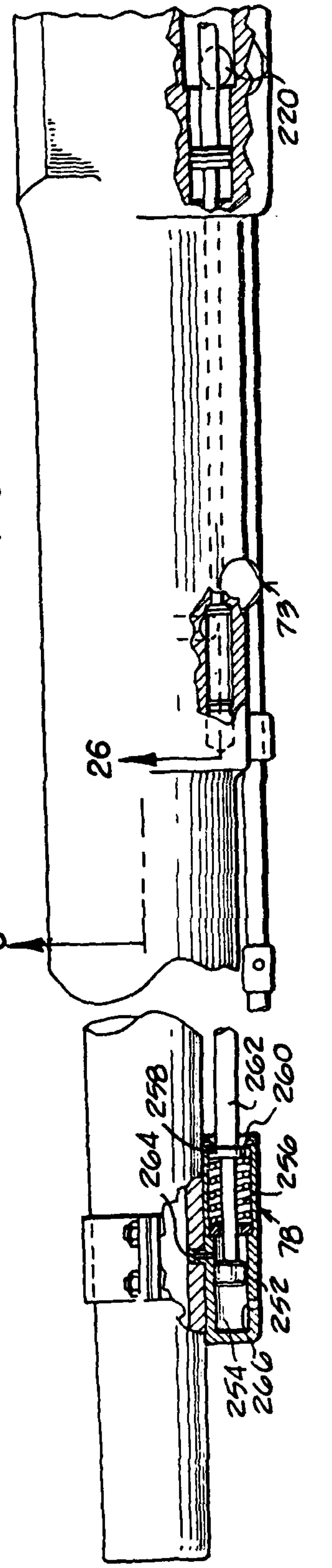

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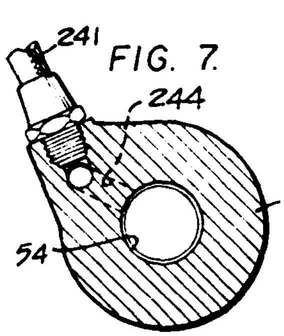
FIG. 5a



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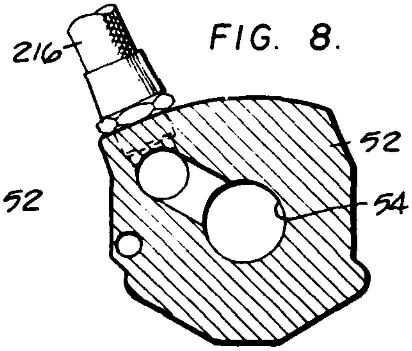

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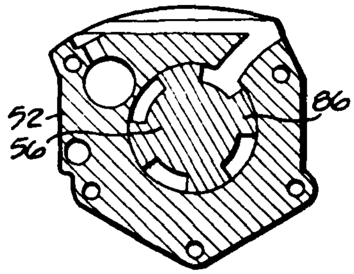

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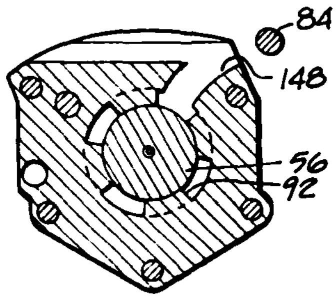

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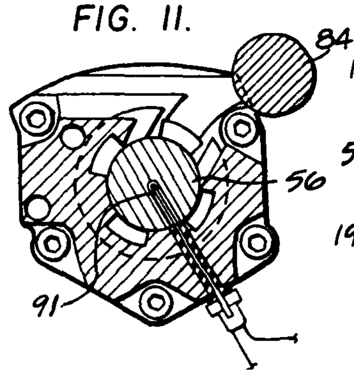


FIG. 11.

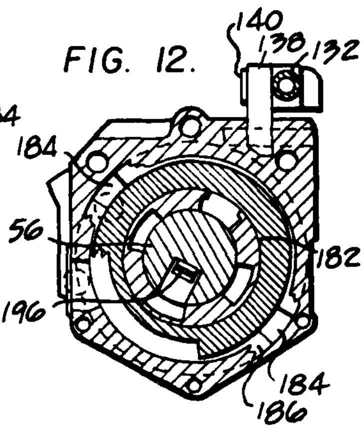


FIG. 12.

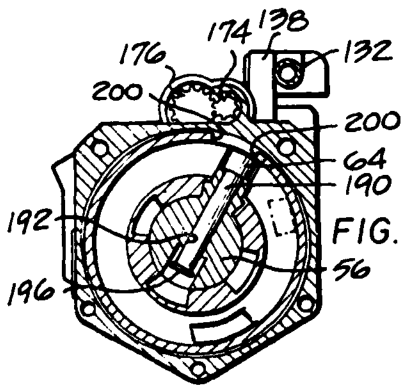


FIG. 13.

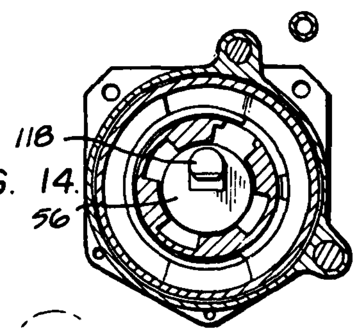
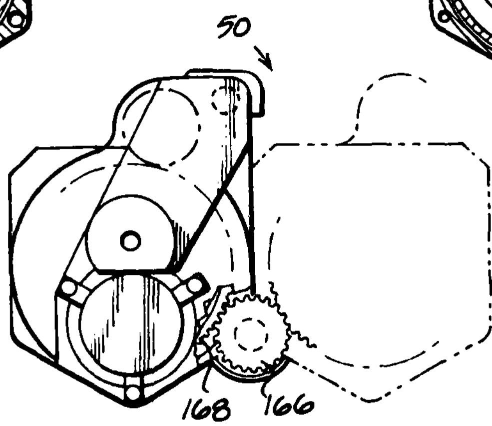


FIG. 14.



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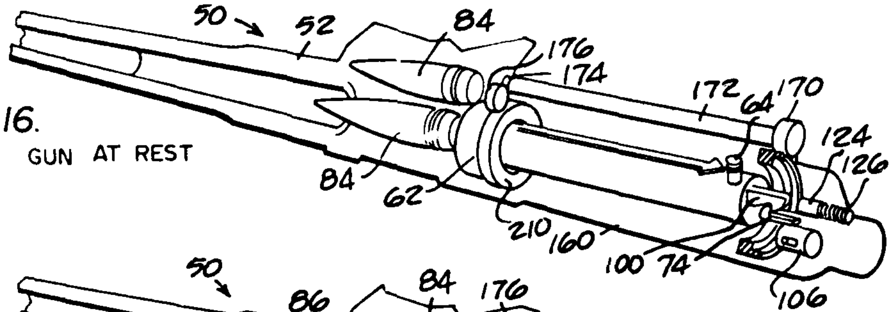


FIG. 16.
GUN AT REST

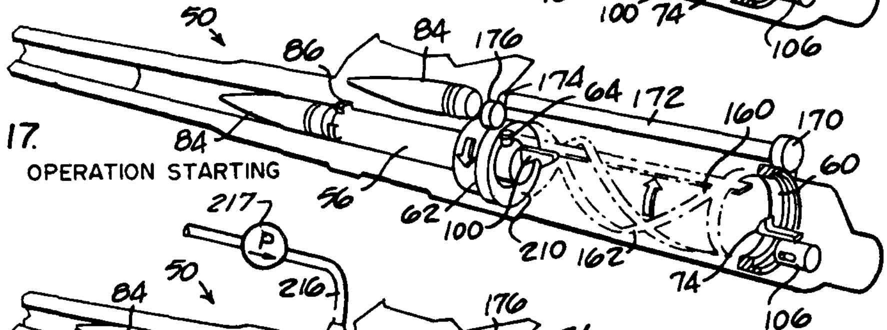


FIG. 17.
OPERATION STARTING

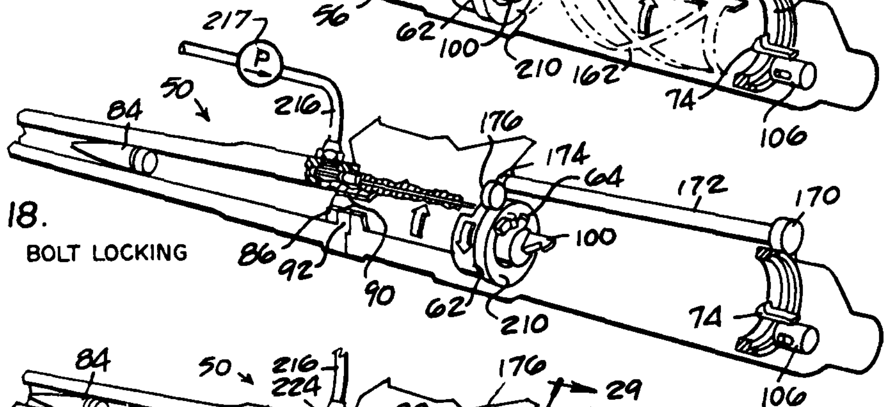


FIG. 18.
BOLT LOCKING

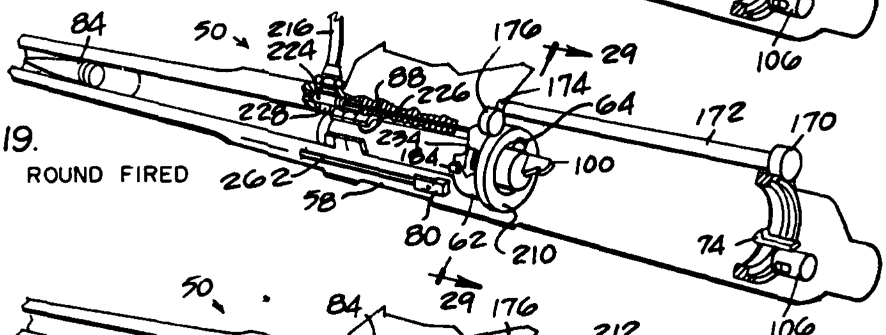


FIG. 19.
ROUND FIRED

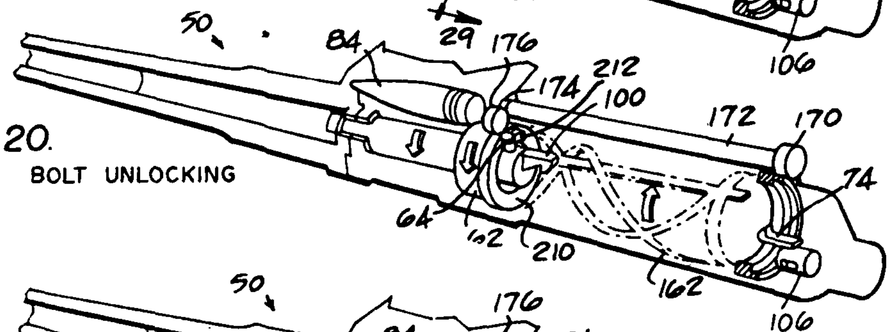


FIG. 20.
BOLT UNLOCKING

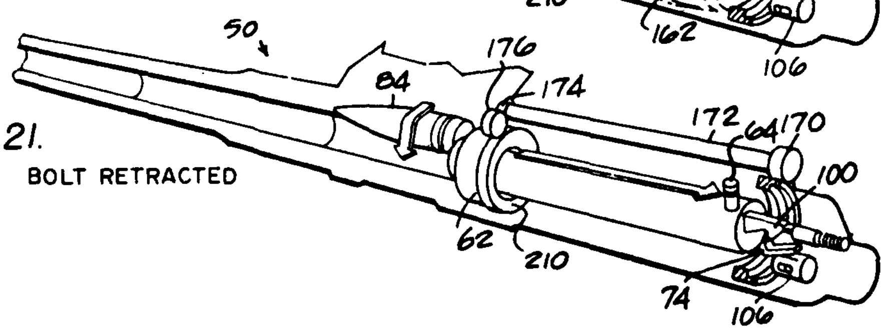
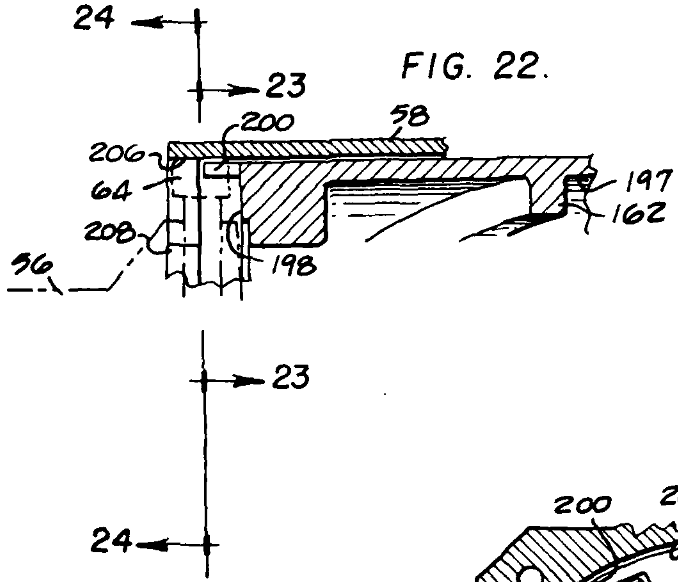


FIG. 21.
BOLT RETRACTED

FIG. 22.



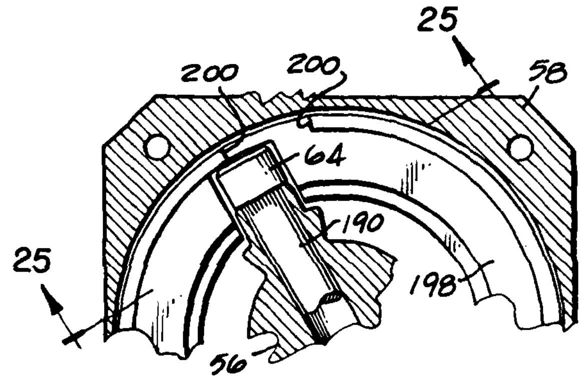


FIG. 23.

FIG. 24.

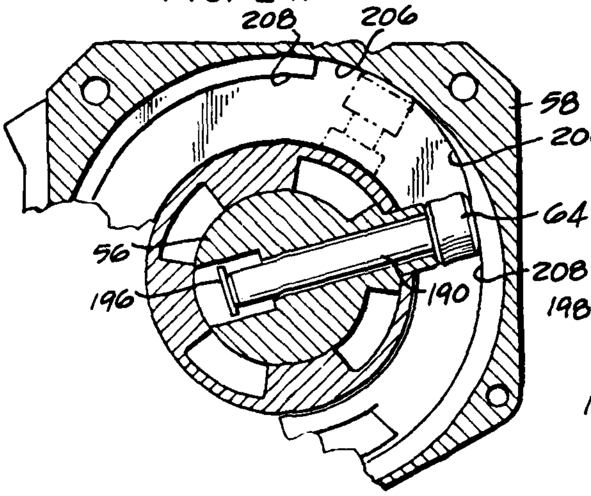


FIG. 25.

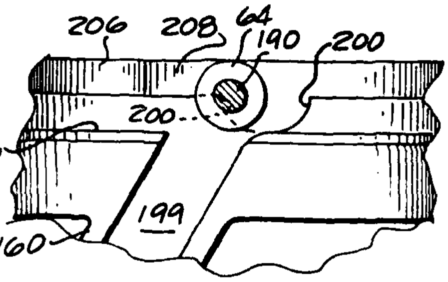


FIG. 26. FIRING POSITION

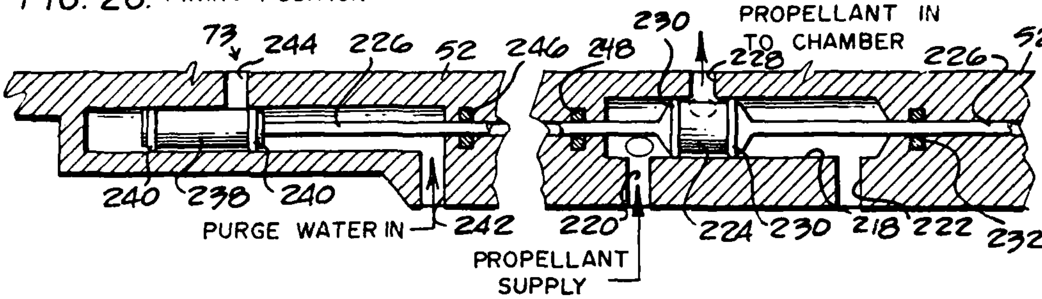


FIG. 27. PROPELLANT LOADING POSITION

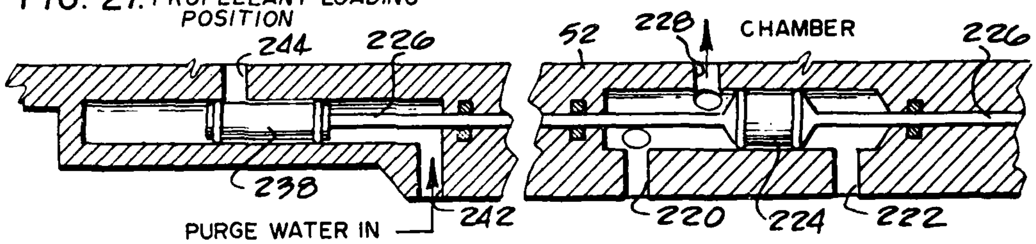
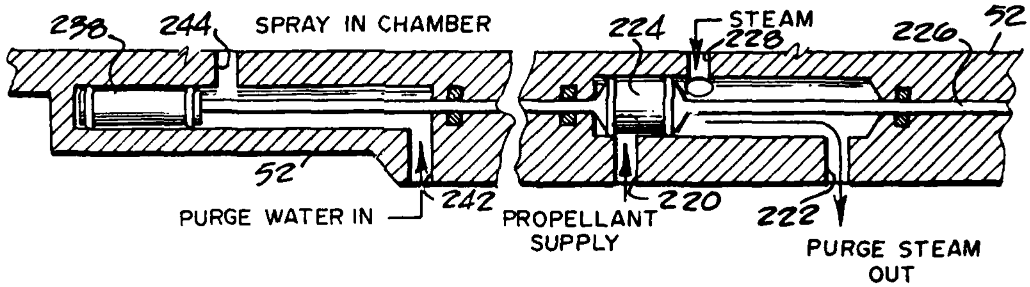


FIG. 28. EMERGENCY PURGE OR COMBUSTION CHAMBER COOLING



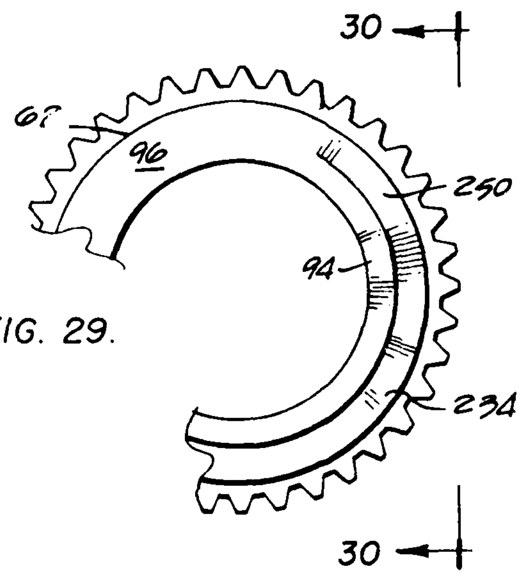


FIG. 29.

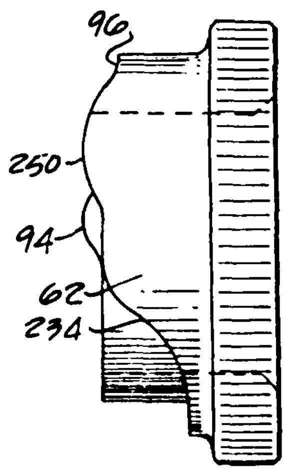


FIG. 30.

FIG. 31.

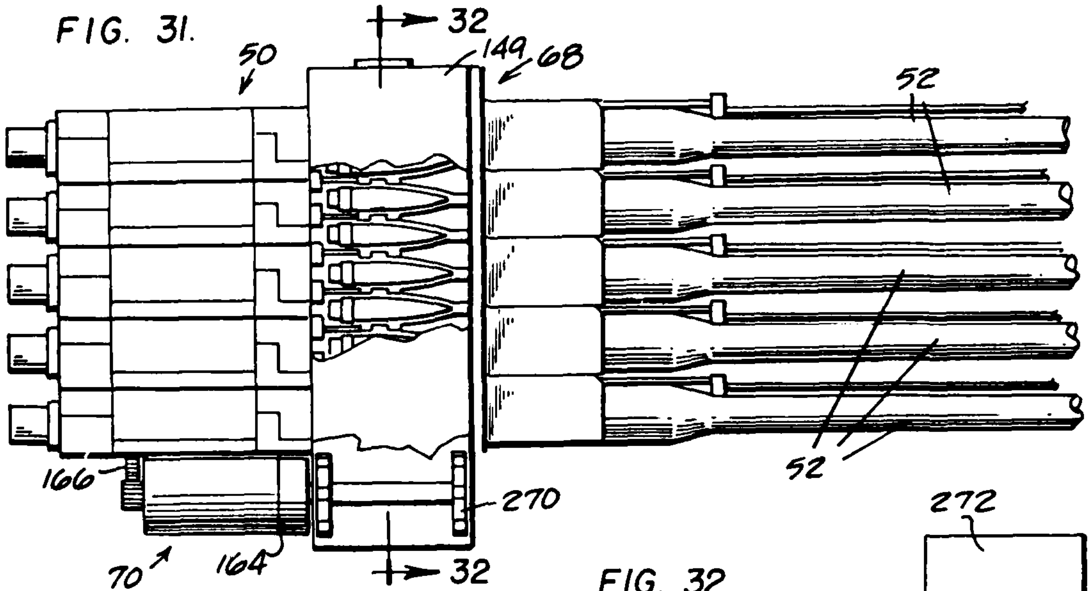


FIG. 32.

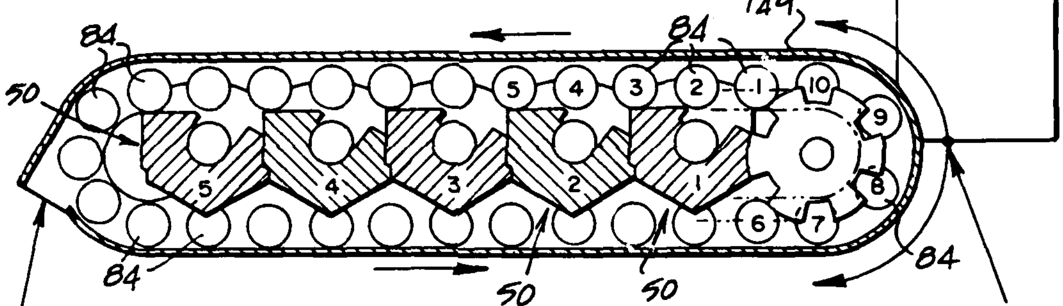
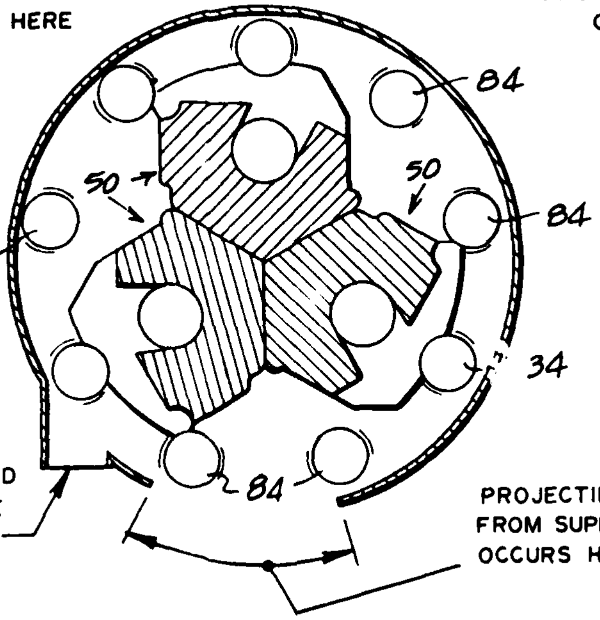


FIG. 33.



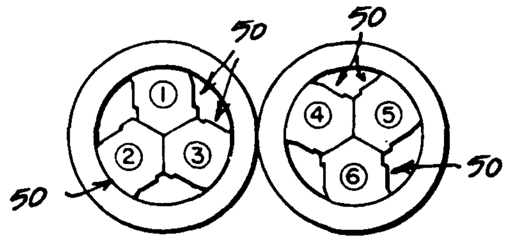
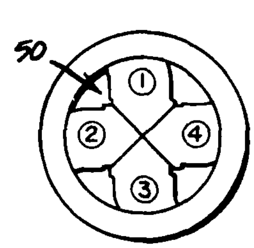


FIG. 34.



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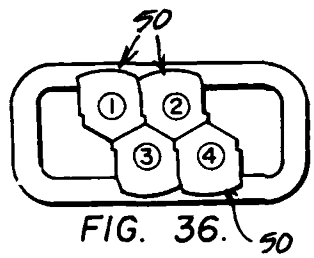

FIG. 36.

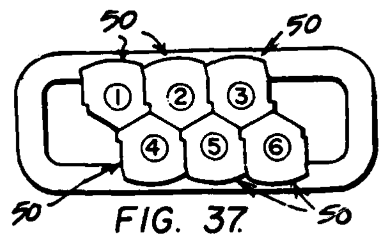

FIG. 37.

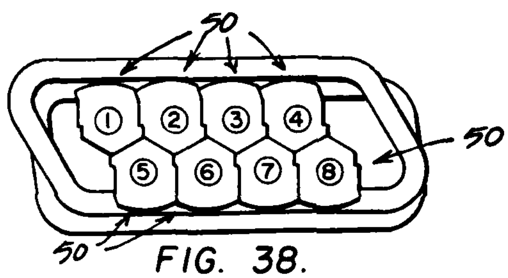

FIG. 38.

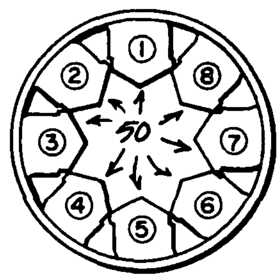

FIG. 39.

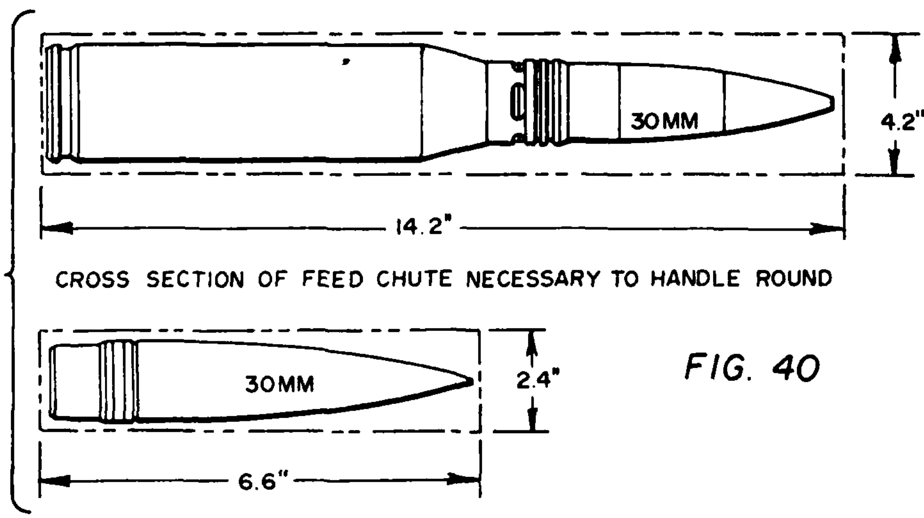

FIG. 40

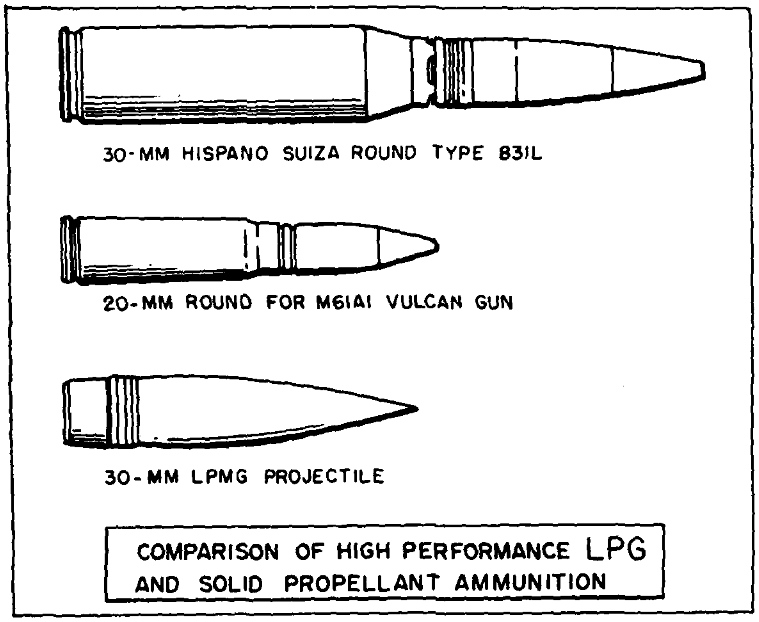

FIG. 41.

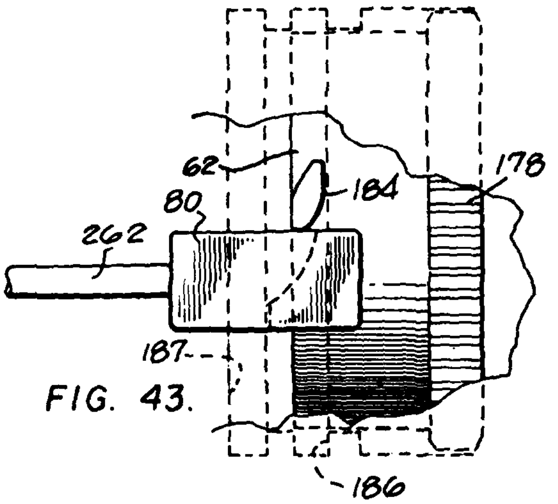

FIG. 43.

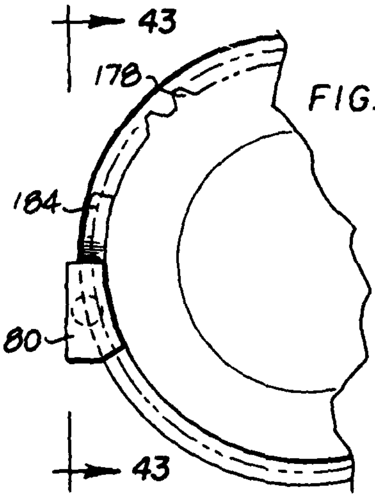

FIG. 42.

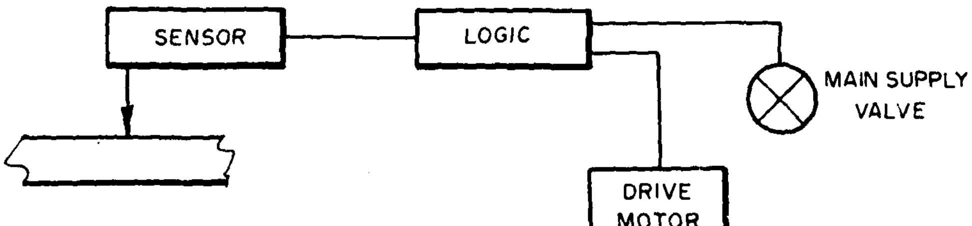

FIG. 44.

LIQUID PROPELLANT MODULAR GUN INCORPORATING DUAL CAM OPERATION AND INTERNAL WATER COOLING

This application is a division of parent application Ser. No. 616,822 filed Sept. 25, 1975 and entitled "Liquid Propellant Modular Gun Incorporating Dual Cam Operation and Internal Water Cooling" and claims the benefit of the filing date of the parent application.

BACKGROUND OF THE INVENTION

This invention relates to a liquid propellant gun of the kind in which liquid propellant is burned in a combustion chamber to fire a projectile from the gun. It relates particularly to a cam operated, externally driven, liquid propellant gun having a slim profile so that a plurality of single barrel gun modules can be conveniently clustered in a variety of configurations. The present invention also relates particularly to an internal water cooling arrangement which injects a small quantity of water into the combustion chamber for cooling by internal vaporization after the firing of each round and which also serves to fill the combustion chamber with water and to purge propellant from the combustion chamber in the event of a misfire.

The present invention has particular utility for high performance, high rate of fire guns in the 20 to 35 mm size. The present invention is not, however, limited to guns of this size.

The existing weapons used by the armed services use solid propellant cartridges. These existing weapons carry the solid propellant in cases, and the cases form a substantial part of the overall weight and overall size of the cartridge. This in itself imposes serious drawbacks and limitations on the installation and use of such weapons, because the projectile feed mechanism and related storage facilities must be large enough and strong enough to store and transport not only the projectile itself but also the related solid propellant and case.

Solid propellants have a further inherent disadvantage because of the fact that solid propellants characteristically develop a high peak temperature. In many gun installations it is necessary to fire long bursts in multiple engagements. Such projected firing schedules produce severe thermal loads on the gun and often cause barrel errosion with the existing solid propellant weapons.

Automatic guns used in antiaircraft roles are a good example of guns subjected to severe firing schedules. Long bursts are needed to achieve high cumulative kill probabilities. These gun systems must also engage multiple targets in rapid succession with little or no time between bursts for adequate cooling. A severe barrel cooling problem results which is a primary factor in limiting system effectiveness. The reduced accuracy associated with premature barrel erosion can effectively destroy gun capability during a single engagement. The alternative is to increase the number of available mounts to achieve an acceptable firing schedule. This results in additional weight, complexity, cost and maintenance problems, and is therefore an unacceptable solution.

The problem has long been recognized in high performance, gun installations such as the U.S. Navy 40 mm Bofors automatic gun and the Oto Melara 76/62. In both cases a classic approach to barrel cooling has been taken, i.e. water jacketing of the exterior barrel surface. However, even with exterior water jacketing, the heat transfer rate may be too limited for some applications.

The problems of severe thermal loads and barrel erosion also occur in drilling by cannon excavation. In cannon excavation the firing rate is relatively low but the duty cycle is sustained for long periods of time, and this produces severe thermal loads on the barrel.

It is one important object of the present invention to provide a more effective means for barrel cooling. This object is achieved in the present invention by internal water cooling. The way in which the internal water cooling is incorporated in a liquid propellant gun of the present invention also permits the mechanism for injecting the water for cooling to be used as a water purge system for purging the combustion chamber of liquid propellant in the event of a misfire, and this system and mode of operation constitutes another, specific object of the present invention. The internal water cooling system will be reviewed in more detail below in the Summary of the Invention and in the Detailed Description of the Preferred Embodiments of the present invention. At this point the applicants would like to point out that, because the water does impinge directly on the heated gun bore surfaces in the present invention, high heat transfer rates are realized and the effectiveness of the internal water cooling permits significant increase in burst length and frequency in automatic guns. It also permits a significant increase in length of the duty cycle in such applications as drilling by cannon excavation.

There are a number of recognized technical objectives for high performance guns. In general, these include: (1) increased velocity and rate of fire; (2) lower gun and ammunition weight; (3) improved interior and exterior ballistic performance; (4) decreased erosion, flash and smoke; (5) reduced recoil loads; (6) elimination of cases, links and sabots; (7) improved reliability and safety; and (8) versatility—application to a wide range or requirements.

In addition to these general improvements, the following characteristics are recognized as being factors lacking in the prior art and needed to enhance the applicability of future gun systems as compared to the prior art: (1) a gun of minimum cross section to assure maximum versatility of installation on shipboard, vehicle and aircraft mounts; (2) an envelope that will assure retrofit capability of single or multibarrel high performance 30 or 35 mm liquid propellant guns in existing 20 mm installations; (3) a mechanism design capable of employing high density, low drag projectiles currently in the inventory or in an advanced stage of development; (4) at the 30/35 mm scale—utilization of existing projectile designs (with only minor modifications) to eliminate immediate requirements for development of new projectiles, and muzzle velocities in excess of 4000 ft. per second employing high sectional density projectiles to provide adequate standoff, short time of flight, and high projectile payload; (5) a gun mechanism construction adaptable to operation at higher muzzle velocities when adequate projectiles are available; (6) stationary barrel construction with rotating cam feed mechanism to provide significant reduction in gun drive power requirements and quicker acceleration to full firing rate; (7) simplified gun harmonization at all firing rates by elimination of tangential projectile velocity components associated with rotating barrel systems.

A further requirement which has been placed on gun development in guns of this size range is that the gun must be applicable across the board to sea, air and ground needs for the three services. These include (but are not limited to) small craft point defense, landing

craft armament, retrofit of existing fixed wing aircraft and antiaircraft and antivehicle ground applications where rate of fire and configuration constraints vary widely. Some missions require single barrel guns with relatively low, adjustable rates of fire (0 to 1000 rpm). Others involve multibarrel installations at intermediate rates of fire (2000 to 3000 rpm), and finally there are those which require very high rates of fire (4000 to 6000 rpm). It can be seen that this range of rate of fire indicates that automatic guns are needed from one to eight barrels.

Liquid propellant guns have a characteristic low peak temperature. Because a liquid propellant will ignite in the bulk mode, it can be ignited, as by an electrical spark device immersed in the liquid propellant, without the need to vaporize the propellant prior to ignition. Liquid propellants are high energy density liquids and can be burned in discrete pulses to produce high combustion pressures. Pulsed burning of a liquid propellant can produce combustion pressures in the range of 10,000 to 80,000 psi and even higher. The magnitude of the average combustion pressure in such pulsed burning can be controlled by the amount of expansion permitted. Higher average combustion pressures can be produced by permitting less expansion.

The liquid propellant gun can produce a flatter combustion chamber pressure-time characteristic than a solid propellant gun. Hence, performance equivalent to a solid propellant gun can be obtained at lower pressure. High cyclic rates of fire are possible with a liquid propellant gun. Because the propellant is a liquid, the propellant can be easily pumped to the firing chamber from a storage area remote from the gun itself. This permits flexibility of installation. Because the cartridge feeding system of the liquid propellant gun carries only the projectile itself, the projectile feed system can be simplified and can be made considerably lighter in weight than for a conventional gun. Or, a considerably larger projectile size and weight can be used for higher performance without having to increase the size of the projectile feed mechanism. This is especially important in permitting larger bore liquid propellant guns to be incorporated in retrofit installations as replacements for existing smaller bore solid propellant guns.

Liquid propellant guns also permit slim profiles which provide desirable configuration versatility. Because the liquid propellant gun permits a low profile, clean exterior design, an individual liquid propellant gun module or a modular grouping of liquid propellant gun modules can be installed in locations that would not accomodate a conventional gun.

It is another important object of the present invention to incorporate the inherent advantages of a liquid propellant gun in a modular gun of the kind incorporating a drive cam and a control cam.

SUMMARY OF THE INVENTION

The liquid propellant gun of the present invention is a cam operated, externally driven gun constructed in modular form. It has a slim profile, and the operational features of the gun are arranged so that the gun can be readily incorporated in a variety of modular clusters, such as flat pack groupings and circular groupings.

The gun barrel is stationary and all combustion chamber pressure loads on the bolt are carried through the barrel rather than being carried through the receiver with the result that the receiver can be made quite light.

The gun incorporates two cams, a drive cam and a control cam.

The drive cam reciprocates the bolt back and forth between a rearward, projectile loading position and a forward, projectile firing position. The drive cam is a hollow cylindrical member having two spiral cam tracks formed on the inside of the drive cam. The first spiral cam track engages a cam follower on the bolt to drive the bolt forward, and the other spiral cam track engages the cam follower to drive the bolt rearward as the drive cam is rotated about the axis of reciprocation of the bolt.

The control cam is located at the front end of the drive cam, and the control cam is also an annular member which is rotated about the axis of the bolt. The control cam controls the injection of the liquid propellant into the combustion chamber and also controls the igniter for igniting the propellant.

The drive cam is rotated faster than the control cam and has dwell or rest areas at each end of the drive cam to provide the time intervals for the projectile loading at one end and the propellant injection and firing at the other end of the bolt's reciprocation.

The drive cam rotates the bolt in one direction at the end of its forward travel to lock the bolt to the barrel, and the control cam rotates the bolt in the opposite direction after firing to unlock the bolt from the barrel.

The axial sliding movement of the reciprocating bolt is guided by lugs on the bolt which interfit in slots in the barrel extension or receiver of the gun.

The cam follower of the bolt is mounted for a limited amount of radial movement with respect to the bolt to accomodate, by outward movement, the bolt rotation required to lock the bolt and, by inward movement, the required dwell at the forward end of the bolt travel. The barrel extension has a cam surface that coacts with the cam follower and a dwell area at the forward end of the drive cam to provide the required dwell in this part of the cycle of operation of the gun. The control cam unlocks the bolt and returns the cam follower to the rearward, spiral drive cam track at the proper time.

The drive cam and the control cam are driven in synchronism by interconnected gearing, and the drive cams of adjacent gun modules are interconnected by idler gears for transferring drive from one module to the next.

The gun of the present invention incorporates a water cooling arrangement in which the control cam causes a small amount of water to be injected into the combustion chamber after the firing of each round. The injected water is vaporized and converted to steam as it contacts the hot combustion chamber structure, and this produces a highly effective cooling of the combustion chamber structure.

The water cooling valving is interconnected with the valving for the propellant injection in a manner such that the combustion chamber can be completely filled with water to purge the combustion chamber of propellant in the event of a misfire.

The gun incorporates misfire detection means which coact with the control cam to completely disengage the control cam from the drive so that operation of the gun module is stopped in the event of a misfire.

Liquid propellant gun apparatus and methods which incorporate the structure and techniques described above and which are effective to function as described above constitute specific objects of this invention.

Other objects, advantages and features of our invention will become apparent from the following detailed description of preferred embodiments taken with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is an isometric view of a liquid propellant gun module constructed in accordance with one embodiment of the present invention;

FIG. 2 is an isometric view showing three of the gun modules of FIG. 1 grouped in a flat pack cluster;

FIG. 3 is an isometric view showing three of the gun modules of FIG. 1 grouped in a circular cluster;

FIG. 4 is a side elevation view of the gun module shown in FIG. 1;

FIG. 5 is an enlarged top plan view of the gun module taken along the line and in the direction indicated by the arrows 5—5 in FIG. 4. In FIG. 5 some parts are partly broken away to show details of construction and FIG. 5a is a continuation of the left hand end of FIG. 5;

FIG. 6 is a side elevation view in cross section taken generally along the line and in the direction taken by arrows 6—6 in FIG. 5 and FIG. 5a. FIG. 6a is a continuation of the left hand end of FIG. 6. The cam follower 64 is shown rotated 30° in FIG. 6 for better illustrating its operation. See FIG. 13 for the true position of this cam follower;

FIGS. 7-14 are end elevation views in cross section taken along the lines and in the directions indicated by the correspondingly numbered arrows in FIG. 6;

FIG. 15 is an end elevation view taken along the line and in the direction indicated by the arrows 15—15 in FIG. 4;

FIGS. 16-21 are isometric views showing the disposition of certain parts of the gun in the various phases of operation indicated by the legends in these figures;

FIG. 22 is a fragmentary, enlarged view of the part of the structure shown encircled by the arrows 22—22 of FIG. 6. In FIG. 22 as in FIG. 6, the cam follower is shown rotated 30° from its actual position illustrated in FIG. 13;

FIG. 23 is a fragmentary, enlarged end elevation view taken along the line and in the direction indicated by the arrows 23—23 in FIG. 22, but with the cam follower at the actual inclination illustrated in FIG. 13;

FIG. 24 is a fragmentary, enlarged end elevation view taken along the line and in the direction indicated by the arrows 24—24 in FIG. 22 showing the cam follower 64 in the unlocked position in phantom outline and in a locked position in bold outline;

FIG. 25 is a fragmentary, enlarged bottom plan view taken along the line and in the direction indicated by the arrows 25—25 in FIG. 23;

FIG. 26 is a fragmentary enlarged side elevation view taken along the line and in the direction indicated by the arrows 26—26 in FIG. 5. FIG. 26 shows the positions of the water injection and the propellant injection control valves during firing of the gun;

FIG. 27 is a fragmentary enlarged side elevation view like FIG. 26 but showing the positions of the water injection and propellant injection control valves during propellant loading;

FIG. 28 is a view like FIGS. 26 and 27 but showing the positions of the water injection and propellant injection control valves during either the combustion chamber cooling or the emergency purge operations;

FIG. 29 is a fragmentary, enlarged view of the front face of the control cam and is taken generally along the line and in the direction indicated by the arrows 29—29 in FIG. 19. FIG. 29 shows the recess in the control cam for the control of the propellant injection, the projection on the control cam for the water injection and a projection on the control cam for controlling the operation of the igniter;

FIG. 30 is a fragmentary enlarged plan view taken generally along the line and in the direction indicated by the arrows 30—30 in FIG. 29;

FIG. 31 is a top plan view showing five gun modules assembled in a flat pack cluster together with a drive motor for the gun modules and the projectile feed system;

FIG. 32 is an end elevational view taken generally along the line and in the direction indicated by the arrows 32—32 in FIG. 31. FIG. 32 shows the feeding of specific projectiles in the endless conveyor belt to related gun modules;

FIG. 33 is an end elevation view like FIG. 32 but showing the projectile feed system for three gun modules assembled in a circular cluster;

FIGS. 34-39 illustrate different cluster configurations for the modular gun of the present invention and illustrate how projectile feed systems are associated with these different cluster configurations;

FIG. 40 is a plan view showing a size comparison for high performance 30 mm liquid and solid propellant rounds of ammunition and also illustrates the relative feed chute sizes required;

FIG. 41 is a top plan view showing a size comparison of a 30 mm liquid propellant projectile, a conventional solid propellant 20 mm round for an M61 Vulcan gun and a conventional solid propellant round for a 30 mm Hispan Suiza round type 831 L. FIG. 41 illustrates how a 30 mm liquid propellant round is approximately the same overall length as a conventional solid propellant 20 mm round and how it is therefore capable of being substituted in conventional projectile feed systems for smaller 20 mm solid propellant rounds with a minimum of retrofit modifications;

FIG. 42 is a fragmentary and elevation view showing details of the misfire switch and control cam shifting lug;

FIG. 43 is a fragmentary side elevation view taken along the line and in the direction indicated by the arrows 43—43 in FIG. 42;

FIG. 44 is a schematic view of a pressure sensing interlock system for stopping operation of a gun module in the event of a drop in propellant feed pressure.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

A liquid propellant gun module constructed in accordance with one embodiment of the present invention is indicated generally by the reference numeral 50 in FIGS. 1, 4, 5, 6 and 16 through 21.

The gun module 50 includes a barrel 52, a combustion chamber 54, a bolt 56, a barrel extension or receiver 58, a drive cam 60, a control cam 62, a cam follower 64, a projectile loading mechanism 66 for loading projectiles from a projectile feeding mechanism 68, a drive mechanism 70, propellant injection means 72, water coolant and purge means 73, a bolt sear 74, an igniter 76, misfire detection means 78 and a misfire switch 80, all as indicated generally by these reference numerals in FIGS. 5 and 6 and in other FIGS. of the drawings.

The gun module 50 illustrated in the drawings uses a liquid monopropellant (i.e. a liquid propellant that con-

tains both a fuel and an oxidizer) in the combustion chamber 54 for firing a projectile 84. It should be noted, however, that many of the features of the present inention are not limited to a modular gun or to a gun using a monopropellant, as will become more apparent from the description to follow.

The bolt 56 is reciprocable back and forth between a rearward, projectile loading position (see FIG. 16) and a forward, projectile firing position (see FIGS. 18, 19 and 20).

The bolt is guided in this reciprocating movement by lugs 86 (see FIG. 17 and FIG. 9) which slide within guide slots 88 (see FIGS. 19 and 11) in the barrel extension 58 and guide slots 90 (see FIG. 18 and FIG. 10) extending through locking lugs 92 at the rear end of the barrel 52.

The igniter 76 is located in the front face of the bolt 56 and comprises an electrode 91 (see FIG. 6 and FIG. 11) which is energized when a cam follower (not illustrated) is displaced by a projection 94 on a forward control face 96 of the control cam 62 (see FIGS. 29 and 30). Energization of the electrode 91 produces electrical energy which ignites the liquid propellant in the combustion chamber 54 to fire the projectile 84 out of the barrel 52. Ignition can also be accomplished by compression ignition or by injecting a chemical into the propellant.

The forward face of the bolt 56 has a seal 96 as best illustrated in FIG. 6.

The rear end of the bolt 56 has a bolt extension 100 which coacts with the projectile loading mechanism 68 to snap a projectile out of a spring clip carrier in the projectile feed mechanism 66 (in a way to be described in more detail below) when the bolt is moved to the rearward, projectile loading position.

The bolt extension 100 also has a detent 102 which is engaged by the pawl of the sear 74 to hold the bolt in the rearward position when the gun trigger is off and a sear solenoid 104 is deenergized.

A sear actuating rod 106 is connected to the rear solonoid 104 and has a slot 108 (see FIG. 6). A pin 110 rides in the slot 108 at the lower end of the pivot arm and is connected at the lower end of the pivot arm 112 of the sear 74. The arm 112 pivots about a sear pivot 114 which straddles the spring cavity. As illustrated in FIG. 6, a spring 116 normally biases the sear pawl 74 toward a bolt retaining position, but energization of the sear solonoid 104 rotates the pawl 74 downward to the bolt releasing position (best illustrated in FIG. 21).

The end face 118 of the bolt extension 100 is engageable with a face 120 of a spring backed part 124 which actuates the projectile loading mechanism 66. The back face of the part 124 provides a spring seat for one end of a bolt return spring 126. (See FIG. 6). The other end of the bolt return spring 126 is seated against an inner face of a rear cover 128.

The part 124 has an upwardly projecting flange 129 which is engageable with an actuator level 130 of the projectile loading mechanism 66. The upper end of the actuator lever 130 is connected to a push rod 132 by a pin joint connection 134, and a spring 136 maintains the lower end of the actuator lever 130 in engagement with the upwardly extending flange 129.

The front end of the push rod 132 is connected to a bellcrank loading lever 138 by a pin joint connection 140. The downwardly extending arm of the bellcrank projectile loading lever 138 is pivotally connected to the barrel extension 58 by a loading lever pivot 141.

The forwardly extending arm of the projectile loading lever 138 has a lower end 142 which is positioned over an upper recess 144 in a spring clip carrier 146 for a projectile 84. This projectile is aligned with the upper end of a projectile receiving passageway 148 in the barrel extension 58 (see FIGS. 10 and 11).

Engagement of the bolt extension 100 with the rod 122 moves the lower end of the actuator lever 130 about the pivot provided by the connection to the spring 136 to shift the rod 132 forward. This pivots the bellcrank 138 about the pivot 141 and snaps a projectile 84 out of the spring clip carrier 146 of the endless conveyor belt 149 (see FIG. 32) of the projectile feed mechanism 68.

The projectile drops into the passageway 148 and into the bore in the barrel extension in front of the bolt 56. Forward movement of the bolt 56 then pushes the projectile up into the barrel 54, and the projectile 84 is then pumped forward (to the position illustrated in FIG. 6) against the forcing cone 150 by the liquid propellant injected into the combustion chamber. This will be described in greater detail below.

The barrel 52 is connected to the barrel extension 58 by cap screws 152 (see FIG. 6).

A cam cover 154 is connected to the barrel extension 58 by cap screws 156 as also shown in FIG. 6.

The drive cam 60 has two internal, spiral shaped, cam paths 160 and 162 which are engageable with the cam follower 64 for reciprocating the bolt 56 forward and backward during operation of the gun. The spiral cam track 160 drives the bolt 56 forward, and the spiral cam track 162 drives the bolt 56 rearward.

The drive cam 60 is axially elongated so that the cam angles are not too high, and the drive cam is rotated faster than the control cam 62.

As best shown in FIGS. 1-3 and 31, the drive system 70 includes a drive motor 164. The drive motor 164 rotates an idler gear 166, and the idler gear 166 is engaged with a gear 168 formed on the outer diameter of the drive cam 60 at the rear end of the drive cam 60.

FIG. 15 illustrates how this same idler gear 166 is used to transfer the drive from one module to an adjacent module in a cluster arrangement.

The drive to the control cam 62 is provided by a jack shaft take off gear 170, a jack shaft 172, a jack shaft pinion gear 174, an idler gear 176 and a gear 178 formed on the outer diameter of the control cam 62 (as best illustrated in FIGS. 6 and 16 through 21). The control cam 62 is therefore rotated in a direction opposite from that of the drive cam 60, as indicated by the arrows in FIG. 17.

In a particular embodiment of the present invention the gear ratios are such that the drive cam 60 is rotated four times as fast as the control cam 62.

The drive cam 60 is mounted for rotation on the barrel extension 58 by bearings 180 at the rear end of the drive cam and 181 at the forward end of the drive cam (see FIG. 6).

The control cam 62 is mounted for rotation on a surface 182 of the barrel extension 58 and is normally retained in a fixed axial position with respect to the barrel extension 58 by two radially projecting cam lobes 184 on the outer periphery of the control cam 62 (see FIG. 12). The lobes 184 travel in an annular groove 186 in the barrel extension 58. In normal operation of the gun the lobes 184 travel in the groove 186 and the control cam 62 is maintained in the fixed axial position illustrated in FIG. 6 with the gear 178 engaged with the gear 176. However, the barrel extension 58 has a re-

lieved space 188 in front of the control cam which permits the control cam to be shifted axially forward and disengaged from the drive connection with the idler gear 176 in the event of a misfire. In this condition of operation as illustrated in FIG. 43 and as will be described in more detail below, the misfire switch 80 engages one of the cam lobes 184 to move the control cam 62 forward. The cam lobe that engages the misfire switch is diverted into a dead end side track 187, and the other lobe 184 enters a relieved area.

As best illustrated in FIGS. 6 and 13, the cam follower 64 is a cylindrical element at the outer end of a rod 190. The rod 190 is mounted for axial movement in a radially extending bore 192 at the back end of the bolt 56. The underside of the bolt 56 has a recessed groove 194, and a leaf spring 196 is mounted in the groove 194 so as to engage the lower end of the rod 190. The spring 196 biases the cam follower radially outwardly and into engagement with associated surfaces on the drive cam 60 and, during part of the time that the bolt 56 is in its forward projectile firing position, with associated large diameter surface 206 and smaller diameter surface 208 on the barrel extension 58. See FIG. 24. This will be described in more detail below.

During forward driving movement of the bolt 56, the outer surface of the cam follower 64 is engaged with a surface 199 of the forward driving cam track 160. See FIGS. 6, 17 and 22. During rearward driving of the bolt 56, the outer surface of the cam follower 64 is engaged with a surface 197 of the spiral cam track 162.

The drive cam 60 has dwell or rest areas at the front and rear ends of the drive cam. The dwell areas provide turnarounds at each end of the bi-directional drive cam.

The rear dwell area includes a surface 201 which is bounded by a rear, radially inwardly extending flange 203 and a forward, inwardly extending flange 205. See FIG. 6. This dwell area at the rear of the drive cam holds the bolt 56 in a retracted position from the time that the cam follower 64 leaves the return cam track 162 until the drive cam is rotated to a position in which an opening in the forward flange 205 permits the bolt return spring 126 and part 124 to shove the cam follower 64 into the forward drive cam track 160.

In a particular embodiment of the present invention (having the 4 to 1 ratio of drive cam revolutions to control cam revolutions for each cycle of operation as noted above), the cam follower 64 rests at the rear dwell area of turnaround for 0.6 turn of the drive cam 60. The forward drive spiral 160 moves the cam follower forward for 0.8 turn of the drive cam 60. The cam follower moves rearward for 0.8 turn of the drive cam and rests at a forward dwell area for approximately 1.8 turns of the drive cam 60.

When the bolt 56 reaches the forward end of its travel, it must be rotated 45° (as illustrated in FIG. 13) to lock the lugs 86 on the bolt in front of the lugs 92 of the barrel 52 (see FIG. 18).

The construction of the forward end of the drive cam 60 and related structure of the barrel extension 58 and back face of the control cam 62 are best illustrated in the enlarged fragmentary view of FIG. 22.

As best illustrated in FIG. 22, when the cam follower 64 leaves the forward end of the forward drive cam track 160, the back side of the cam follower 64 is positioned in a forward dwell area 198 so that continued rotation of the drive cam 60 cannot produce any continued forward movement of the bolt 56.

The drive cam 60 does, however, have a slot 200 (see FIGS. 22 and 23) located at the forward, outlet end of the forward cam track 160 so that the spring 196 (see FIG. 6) shoves the rear half of the cam follower 64 outward and into this slot 200 as soon as the forward reciprocation of the bolt has been completed. The rotation of the drive cam 60 in the clockwise direction indicated by the arrow in FIG. 17 then rotates the cam follower and bolt 45° to the locking position illustrated in FIG. 18.

At the same time that the back half of the cam follower 64 moves into the slot 200, the front half of the cam follower 64 engages the large diameter surface 206 (see FIG. 24) of the barrel extension 55. This surface 206 has a ramp 206a which decreases in diameter, as the bolt is rotated 45° to the locked position, until the diameter is the same as that of the surface 208. This ramp 206a pushes the cam follower 64 downward from the outwardly extended position shown in phantom outline in FIG. 24 to the retracted position shown in solid outline in FIG. 24.

The surface 208 thereafter engages the top of the front half of the cam follower 64 to retain the cam follower 64 in the retracted position and within the groove 198 of the drive cam 60 until the firing of the projectile from the combustion chamber 54 has been completed and the bolt 56 is ready to be rotated back 45° to an unlocked position and then retracted to the projectile loading position by engagement of the cam follower 64 within the rear drive cam track 162.

While the cam follower 64 is retained in the retracted position illustrated in FIG. 24 by the stationary engagement of the cam follower 64 with the surface 208 at the end of the ramp 206, the drive cam 60 is of course continuing to rotate with respect to the cam follower 64 with the back half of the cam follower 64 engaged in the relieved area of the recessed face 198. At the same time the rear face 210 of the control cam 62 is rotating counter clockwise with respect to the cam follower 64, as illustrated by the arrows in FIGS. 18 and 19.

The rear face 210 of the control cam has a bolt unlocking and return wedge 212 projecting outwardly from the rear face 210. As this wedge rotates into engagement with the cam follower 64, it first of all rotates the cam follower and bolt 45° counter clockwise (as viewed in FIG. 20) to unlock the bolt by aligning the lugs 86 with the slots 90. Continued rotation of the control cam 62 then moves the cam follower 64 axially to the rear and into the front inlet end of the rear dirve cam track 162, as this end of the cam track 162 opens to the front dwell area 198. Continued rotation of the drive cam 60 then reciprocates the bolt 56 to a rearward, projectile loading bolt position.

The gun 50 as illustrated in the drawings uses a liquid monopropellant, i.e. a liquid propellant having both a fuel and an oxidizer. Mixtures of hydrazine, hydrazine nitrate and water are examples of monopropellants that may be used. However, propellants developed for torpedo application have physical, performance, handling and safety characteristics that are well suited for use in the present invention This is understood since torpedo propellants must be compatible with the long duration, closed environment of a submarine where adverse characteristics from the standpoint of toxicity, handling or safety are completely intolerable. The liquid propellant is stored, either adjacent to the gun 50 or remotely, and is conducted to the propellant injection means 72 by a flex conduit 216 as shown in FIGS. 18 and 19. The

propellant supply pressure is supplied either by pump or by an accumulator subsystem (not illustrated). The accumulator is preferable from the standpoint of being effective in reducing pump volume requirements while meeting the peak flow rates necessary for burst fire. The propellant supply system includes a pressure sensing interlock system (see FIG. 44) which senses the propellant pressure by means of a sensor and stops operation of the complete group (row or cluster) of gun modules by closing a main propellant supply valve and stopping operation of the drive motor when the supply pressure drops below an established level. This prevents incomplete propellant filling.

The porting and valving arrangement for controlling the injection of liquid propellant into the combustion chamber **54** is best shown in FIGS. **5, 8, 18** and **26–28** of the drawings.

As best illustrated in FIG. **26**, the sidewall of the barrel **52** has an axially extending bore **218** at one side of the combustion chamber **54**, and the propellant conduit **216** is connected with a port **200** at one end of the bore. A port **222** connects the other end of the bore to drain.

A spool valve **224** is mounted for axial movement within the bore **218**, and the control of the position of the spool valve **224** is provided by a valve control rod **226** which is connected to the valve spool **224** at one end. The other end of the rod **226** is engaged with the front face **96** (see FIG. **29**) of the control cam **62** and acts as a cam follower.

A port **228** connects the axial bore **218** with the combustion chamber **54**.

The valve spool **224** has annular seals **230** at each end of the spool and the rod **226** is sealed by a seal **232** as illustrated in FIG. **26**.

The cam face **96** of the control cam **62** is formed with a recessed ramp **234** which controls the duration of the time period for injection of the liquid propellant through the ports **220** and **228**. The control rod **226** is biased (by the propellant supply pressure) to the right (as viewed in FIG. **26**) so that the cam follower end of the rod **226** is maintained in engagement with the face **96** of the rotating control cam **62**.

In the firing position, the valve spool **224** is positioned by the control rod **226** to block off the port **228** (as illustrated in FIG. **26**).

FIG. **27** illustrates the position of the valve spool **226** with respect to the port **228** when the recess **234** of the control cam **62** has been rotated to a position in which the control rod **226** first drops down into the recess **234**. The valve spool **224** is shifted to the right in the bore **226** to open the port **228** for communication with the port **220**, and the liquid propellant flows into the combustion chamber under the pressure of the propellant supply system. The pressure of the inflowing propellant pumps the projectile **84** forward to the position illustrated in FIG. **6a**. The inclined ramp in the recess **234** pushes the control rod **226** leftward and back to the position illustrated in FIG. **26** as the cam follower end of the control rod **226** returns to the plane of the front face **96** of the control cam **62**. The amount of liquid propellant injected is therefore determined by the pressure of the propellant supply system and the length and angular inclination of the recess **234**.

As illustrated in FIG. **29**, the front face **96** of the control cam **62** has a projection **94** which is engaged by a spring biased cam follower. The electrode **92** is energized as the igniter cam follower is actuated by the projection **94** following the filling of the combustion chamber **54** with the liquid propellant.

A very important feature of the present invention is the internal water cooling provided by the coolant injection means **73**.

The coolant injection means **73** inject a small quantity of water directly into the firing chamber **54** between rounds. Since water impinges directly on the heated gun bore surfaces, high heat transfer rates are realized. The effectiveness of the internal water cooling permits a significant increase in burst length and frequency in the case of an automatic gun fired at high cyclic rates and permits a significant increase in the length of the duty cycle of guns used at lower cyclic rates such as in common excavation.

In a specific embodiment of the present invention water is used as the cooling liquid because it has a high heat of vaporization and is readily available. Other liquid coolants can of course be used, but the description to follow will be directed specifically toward the use of water as the coolant liquid.

One embodiment of the valve structure for accomplishing the internal water cooling is illustrated in FIGS. **5** and **26–28**. As illustrated in these drawings, the wall of the gun barrel **52** has an axially extending bore **236**. A valve spool **238** is mounted for reciprocation within the bore, and the valve spool has seals **240** at each end.

A water inlet port **242** is connected to one end of the bore **236** and a hose is attached to this port **242** to connect the port to a pressurized water supply system.

A port **244** connects the bore **236** to the combustion chamber **54**.

The valve spool **238** is connected directly to the valve spool **224** through an extension of the rod **226** so that the water coolant valve spool **238** moves in unison with the propellant injection valve spool **224**.

Seals **246** and **248** seal off the part of the rod **226** extending between the bores **236** and **218**.

In the firing position of the valve spools (as illustrated in FIG. **26**) the valve spool **236** blocks flow of water into the port **224** and flow of combustion gases out of the port **244**.

Similarly, the water injection valve spool **238** is positioned in the propellant loading position illustrated in FIG. **27** to block flow through the port **244**.

However, immediately after firing, the control cam **62** rotates to a position in which a projection **250** shifts the control rod **226** leftward (as viewed in FIG. **28**) by an amount sufficient to open the port **244**. This projection **250** permits a short time period for the injection of coolant water into the combustion chamber (through the passageway provided by the ports **242**, the bore **236** and the port **244**) before the cam follower end of the control rod **226** moves down off the projection **250** and back onto the plane of the face **96**. This small amount of water is vaporized by the hot wall structure of the combustion chamber and turned to steam. During this water injection period, the port **228** may be maintained closed by the land **224** or, depending on the size of the projection **250**, the port **228** may also be opened for venting of gas and steam from the combustion chamber (through the port **228** and the bore **218** and the vent port **222**).

Thus, immediately after firing each round, the coolant injection means **73** are opened and a metered quantity of water is injected directly on the forward portion of the combustion chamber **54**. The water spray is directed toward the combustion chamber surfaces of the

gun. The quantity of water is metered to insure that virtually all of it is converted to steam.

The next projectile **84**, in the process of being loaded and pumped forward in the chamber, pushes any steam and water remaining in the chamber ahead of the projectile into the barrel. After firing, the residuals are forced out of the barrel by the projectile as it traverses the bore.

If the distribution of the water vapor in the bore is assumed to be the same as the normal products of combustion of a liquid propellant, the weight of gas (vapor) being pushed out by the projectile is slightly less than that for a conventional solid propellant round. This results from the somewhat lower molecular weight of liquid propellant combustion products and that of the water vapor.

The internal water cooling is optimized to inject no more water than is vaporized. Hence, there is no penalty for acceleration inert mass. The water injected is controlled by the dwell of the surface **250** of the control cam **62**.

Heating and cooling of a gun barrel bore surface is highly transient. The analysis of the instantaneous heat transfer process is complex and methods for accurately determing the heat transfer coefficient controlling the process are not well established. However, the following example, based on average conditions, does illustrated the effectiveness of the internal water cooling.

Considering a 35mm 4,000 ft/sec muzzle velocity liquid propellant gun, the significant characteristics are:

Projectile Weight; 1.2 lb.
Muzzle Velocity; 4,000 ft/sec.
Propellant Charge; 1 lb.
Projectile Muzzle Kinetic Energy; 298,000 ft.-lb.
Firing Rate; 750 rounds per minute

Estimates of barrel heating per round are calculated using the criteria established by Corner[1] where the heat loss Q is:

$$Q = X(\tfrac{1}{2} W_1 V^2)$$

W_1 = "Effective" Mass of the projectile
V = Muzzle velocity
$X \cong 0.3$ (maximum value)

[1] "Theory of the Interior Ballistics of Guns". J. Corner. Pg. 141 John Wiley & son.

For the characteristics of the 35mm 4,000 ft/sec LPG, Q = 125,000 ft.-lb. (of 161 B.t.u.).

Gun barrel cooling is accomplished by direct water injection on the interior heated surfaces. Assuming initial water temperature to be 70° F., the heat absorption capability of the injected water (including specific heat and heat of vaporization) is approximately 1,110 B.t.u./lb. The quantity of water required for complete cooling after each round is then =

$$\frac{161 \text{ B.t.u./round}}{1110 \text{ B.t.u./lb.}H_2O} \text{ or } .146 \frac{\text{lb.}H_2O}{\text{round}}.$$

In a rapid fire automatic weapon, the time available for cooling between rounds is limited by heat transfer rate. At a firing rate of 750 rounds per minute, the cycle time per round is 80 milliseconds.

The heat transfer rate can be estimated from the following:

$$q = hA\Delta T$$

q = rate of heat transfer B.t.u./hr.
h = heat transfer coefficient B.t.u./hr. of ft^2
A = area ft^2
ΔT = temperature difference ° F.

For estimating the heat transfer rate, the following assumptions are made:

(a) ΔT

Bore surface temperature rises of 1,200–1,400° F. in one millisecond have been measured in liquid propellant guns at the origin of rifling. Since rapid injection of cooling water immediately after firing is involved in the present method, large average temperature differences will exist during the cooling process. Here a conservative ΔT of 500° F. is assumed.

(b) Area

The chamber bore surface area is 0.375 ft^2. It is assumed that the injected cooling water is effectively sprayed over an area at least equivalent to this, therefore, the effective area is assumed to be 0.375 ft^2.

(c) Heat Transfer Coefficient

Water sprayed against hot surfaces boils violently and is rapidly vaporized. Boiling heat transfer coefficients are quite high. Coefficients of ~**300,000** B.t.u./hr.ft^2° F. are common. Here, the heat transfer coefficient conservatively is assumed to be 250,000 B.t.u./hr.ft^2° F. Based on these considerations, the rate of heat transfer is estimated to be:

$$q = \left(250{,}000 \frac{\text{B.t.u.}}{\text{hr. ft}^2\ ^\circ\text{F}}\right)(.365 \text{ ft}^2)(500^\circ \text{ F.}) = 4.7 \cdot 10^7 \frac{\text{B.t.u.}}{\text{hr.}}$$

$$\text{or } 1.3 \times 10^4 \frac{\text{B.t.u.}}{\text{sec}}$$

Since complete cooling per round requires removal of 161 B.t.u. the required cooling time is:

$$t = \frac{161 \text{ B.t.u.}}{1.3 \cdot 10^4 \frac{\text{B.t.u.}}{\text{sec}}} = 12.4 \text{ milliseconds}$$

With a total cycle time per round of 80 milliseconds there is ample cooling time available.

The above example is idealized in that perfect distribution of the cooling water over the heated surfaces is assured. While complete cooling is not usually attained in practice, a substantial portion of the heat imparted to the gun is removed. This has a major impact on firing schedule and gun system effectiveness.

FIG. **28** illustrates the disposition of the valve spools **238** and **224** in the event of a misfire, when it is desired to purge the combustion chamber **54** of all liquid propellant within the combustion chamber. In this event, the entire control cam **62** is shifted axially forward by the misfire detection switch **80**, and this shoves the control rod **226** leftward to the position illustrated in FIG. **28** where the valve spools **238** and **224** are held in the positions illustrated. The coolant water flows continuously into the combustion chamber through the coolant inlet port **244**, fills the combustion chamber **54** completely with water, and purges out all of the liquid propellant through the port **228** and the vent **222**.

A timing device, not illustrated, shuts off the flow of water through the hose **241** (see FIG. **7**) after a period of time sufficient to insure complete purging of the combustion chamber.

As described above in this specification, the misfire switch **80** is controlled by the misfire detection means **78** (see FIG. **5**).

The misfire detection means **78** include a gas piston **252** mounted for reciprocation within a cylinder **254** and spring biased by a spring **256** rightward (as viewed in FIG. 5) to the position illustrated in FIG. **5** where a flange **258** engages a snapring stop **260**.

A connecting rod **262** connects the gas piston **252** to the misfire switch **80** so that the misfire switch **80** is normally spring biased to the position illustrated in FIG. **5** in which the misfire switch **80** is axially aligned with the lobes **184** on the control cam **62**.

A port **264** connects the bore of the barrel **52** with the interior of the cylinder **254** at the back face of the gas piston **252**.

A vent port **266** is located in the sidewall of the cylinder to vent the interior of the cylinder **254** to atmosphere.

As a projectile is fired from the gun, the pressurized gases behind the projectile flow through the port **264** to momentarily move the gas piston **252** forward (leftward as viewed in FIG. **5**) within the cylinder **254**. This pulls the misfire switch **80** forward and out of alignment with the lobe **184** on the control cam long enough to let this lobe rotate past the misfire switch without engaging the misfire switch **80**.

However, if there is a misfire, the gas piston **252** remains stationary and the misfire switch **80** engages the cam lobe **184** to divert the cam lobe into a dead side track **187** (see FIG. **43** and FIG. **6**) while the other cam lobe **184** enters a relieved area. This moves the control cam **62** axially forward in the recess **188** (see FIG. **6**) to disengage the gear **178** from the idler gear **176**, and the rotation of the control cam **62** is stopped.

The timing of this action leaves the bolt **56** in a locked position with the breach closed.

In addition, as pointed out above, forward motion of the control cam **62** pushes the propellant fill valve **224** forward, exposing the combustion chamber fill port **228** to the port **222** at the rear of the bore **218** to permit purging of the liquid propellant from the combustion chamber **54**. At the same time the water inlet valve **238** is moved forward to open the water injection port **244**, and water is purged through the combustion chamber **54** to prevent cook off and to make the round inert.

The control cam disengagement disables that particular gun module but it does not disable the drive cam power train. Therefore, other modules in the banked row or cluster continue to operate and fire. Operation in this limited condition can continue until servicing. Projectiles intended for loading but passing over the disabled module are ejected at the end of the feed system transfer region.

If a projectile is missing at the feed system conveyor, a mechanical interlock system leaves a retainer in the path of the propellant fill valve **224** to prevent the valve from opening. As the module continues in a cycle of operation, a pseudo misfire occurs, and the module is disabled as described above.

Since complete propellant filling depends on fluid pressure in the propellant supply system with the monopropellant injection system described above, insufficient pressure of the propellant supply system could result in incomplete propellant filling. In the present invention when the supply pressure inadvertently drops below an established level, a pressure sensing interlock system (see FIG. **44**) stops operation of the complete group (row or cluster of modules).

The projectile feed system is best shown in FIG. **31**. The projectile feed mechanism **68** employs a short endless conveyor **149** which is driven by a sprocket drive **270** from the drive motor **164**.

As best illustrated in FIG. **32**, the conveyor **140** mates with a transfer mechanism **272** to accept projectiles **84** from a conventional belt or linkless feed. The transfer mechanism **272** includes a shifting device which selects from separate projectile supplies to switch types of ammunition. The spring clip cradles **146** are the primary elements of the conveyor **149**. The tangs on the ends of the spring clip cradles slide in guide grooves in the conveyor frame. The cradles are coupled to form an endless, flexible chain.

Two configurations of the conveyor **149** are illustrated in FIGS. **31-32** and in FIG. **33**. In FIGS. **31** and **32** a flat conveyor passing over a banked row of modules is illustrated and in FIG. **33** a circular conveyor wrapping around a cluster of three modules is illustrated.

The flat conveyor configuration shown in FIGS. **31** and **32** demonstrates the loading scheme of the present invention which depends on a unique sequencing arrangement. In FIG. **32** a banked row of five modules served by the conveyor **149** are indicated by the reference numerals **1-5**. The projectiles **84** move along the conveyor from right to left and are numbered in groups of five, e.g. (5, 4, 3, 2, 1), (10, 9, 8, 7, 6), etc. The modules are also numbered (5, 4, 3, 2, 1) and are loaded in the sequence 1 through 5 and fire, of course, in the same sequence. Center-to-center spacing of the projectiles in the conveyor (1.75 in. for 30mm) is ½ the center-center spacing of the modules (3.5 in. for 30mm).

Assume projectile **1** is at the loading position for module **1**. The loading lever on the module kicks the projectile out of the conveyor and into the module. The conveyor travels 1.75 inches between loadings. Projectile **2** was 1.75 inches away from the loading position for module **2** at the start but has now arrived in position and is loaded. Projectile **3** is now 1.75 inches away from the module **3** and will arrive at the loading position on time. The loading progresses until projectile **5** is loaded in module **5**, this projectile having moved 7.0 inches while the other projectiles were loading. By the time projectile **5** has been loaded, projectiles **10, 9, 8, 7** and **6** have moved into positions occupied by projectiles **5, 4, 3, 2** and **1** at the start. The process continues in perfect time, with projectile **6** loading into module **1**, projectile **7** loading into module **2**, etc. This loading scheme applies to any number of modules.

The circular conveyor for a cluster of three modules, shown in FIG. **33**, uses the same loading scheme as described above. Since the conveyor is circular, the cradles can take the form of pockets in a wheel-like structure. A minimum of six cradles or pockets are needed to properly feed the cluster. Nine pockets are shown in FIG. **33** to reduce the rotational speed of the conveyor and the centrifugal force imposed on the projectiles, thus reducing the force that must be exerted by the projectile loading levers at the modules.

Other cluster configurations as illustrated in FIGS. **34-39** are readily arranged and serviced by the projectile loading mechanism **68** as described above.

The modular system of the present invention can accomodate recoil adapters similar to those on the M—**61** gun to reduce recoil forces. A banked row or cluster or modules can be supported mutually at the breach end of the barrels by a bracket structure that receives a pair (or more) of recoil adapters. An addi-

tional bracket structure mutually supports the rear of the modules and engages a short fixed slide to accomodate recoil travel. The latter bracket includes a provision for boresighting.

The impact of caseless operation on gun design is best illustrated in FIG. 41 which compares a 30mm liquid propellant modular gun projectile with a conventional 20mm round for the M-61 gun. Due to the similarity in length and diameter between the liquid propellant projectile and the solid propellant round, it is feasible to directly substitute the 30mm projectile for the existing 20mm cartridge. Some modifications are, of course, required due to slight differences in configuration but the overall volume is substantially the same.

FIG. 40 compares the diameters of a liquid propellant modular gun projectile in a 30mm size with the cartridge and projectile size for a conventional 30mm solid propellant round. This figure graphically illustrates the space and weight savings which can be achieved for the projectile feed systems in the 30mm gun size with the liquid propellant modular gun of the present invention.

While we have illustrated and described the preferred embodiments of our invention, it is to be understood that these are capable of variation and modification, and we therefore do not wish to be limited to the precise details set forth, but desire to avail ourselves of such changes and alterations as fall within the purview of the following claims.

It is claimed:

1. An automatic gun of the kind in which liquid propellant is burned in a combustion chamber to fire a projectile from the gun and comprising,

cyclic means for automatically loading and firing individual projectiles one-by-one in sequence so long as the gun is operated in a trigger on condition,

said cyclic means including a rotatable, mechanical control element,

misfire detection means for detecting a misfire of a projectile during the automatic firing mode of operation and operatively associated with the cyclic means to stop operation of the cyclic means, after detection of a misfire, by moving the rotatable, mechanical control element of the cyclic means out of operative engagement with the rest of the cyclic means.

2. The invention defined in claim 1 wherein the rotatable, mechanical control element is a control cam and the misfire detection means move the control cam to a position in which the control cam is disengaged from the rest of the cyclic means after the detection of a misfire.

3. A method of stopping automatic operation of a liquid propellant gun of the kind having a cyclic mechanism which includes a rotatable, mechanical control element for automatically loading and firing individual projectiles one-by-one in sequence so long as the gun is operated in a trigger on condition, said method comprising,

detecting a misfire of a projectile during the automatic firing mode of operation, and

stopping operation of the cyclic mechanism, after detection of the misfire, by moving the rotatable, mechanical control element part of the cyclic mechanism out of operative engagement with the rest of the cyclic mechanism.

* * * * *

United States Patent [19]

Elmore et al.

[11] 4,164,890

[45] Aug. 21, 1979

[54] **LIQUID PROPELLANT MODULAR GUN INCORPORATING DUAL CAM OPERATION AND INTERNAL WATER COOLING**

[75] Inventors: **Lester C. Elmore**, Portola Valley, Calif.; **Thomas M. Broxholm, deceased**, late of Palo Alto, Calif., by Anne K. Broxholm, administratrix

[73] Assignee: **Pulsepower Systems, Inc.**, San Carlos, Calif.

[21] Appl. No.: **834,688**

[22] Filed: **Sep. 19, 1977**

Related U.S. Application Data

[62] Division of Ser. No. 616,822, Sep. 25, 1975, Pat. No. 4,062,266.

[51] **Int. Cl.**^{2} **F41D 3/06; F41F 11/00**

[52] **U.S. Cl.** **89/185**; 89/7; 89/11

[58] **Field of Search** 89/7, 11, 12, 185

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Primary Examiner—David H. Brown

Attorney, Agent, or Firm—Donald C. Feix

[57] **ABSTRACT**

A liquid propellant modular gun has a slim profile and is constructed for wide latitude in gun cluster configuration.

The modular gun has a stationary barrel and is externally driven and cam operated by a drive cam and a control cam.

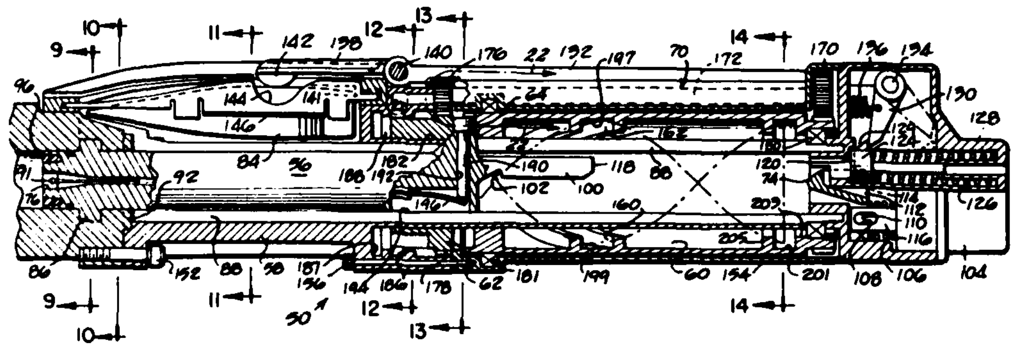
The drive cam has one internal spiral cam track for driving the bolt forward to a projectile firing position and another internal spiral cam track for driving the bolt rearward to a projectile loading position.

The control cam is mounted for rotation at the forward end of the drive cam and controls the injection of liquid propellant into the combustion chamber and an electrical igniter.

A water injection mechanism is also associated with the control cam for injecting a small amount of water into the combustion chamber after the firing of each round to cool the combustion chamber structure by internal water cooling. The water injection mechanism is also effective to purge propellant from the combustion chamber in the event of a misfire.

The bolt is rotated to a locked position at the forward end of its travel where locking lugs on the bolt are engaged with mating lugs on the barrel so that all breach loads caused by chamber pressure are carried through the barrel rather than the receiver. This permits the receiver to be made quite light.

5 Claims, 44 Drawing Figures



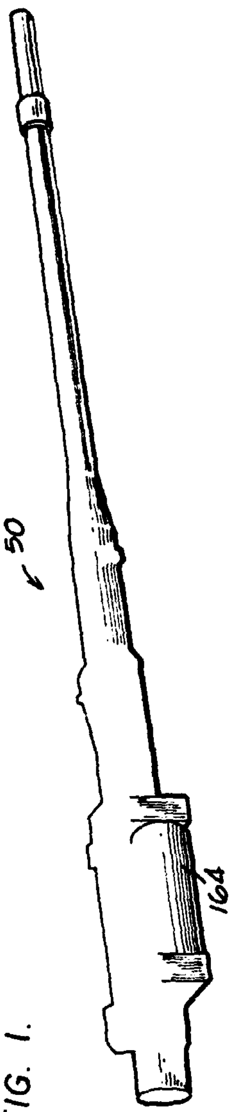


FIG. 1.

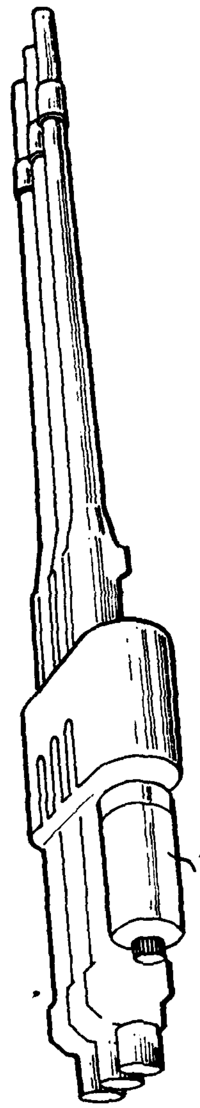


FIG. 2.

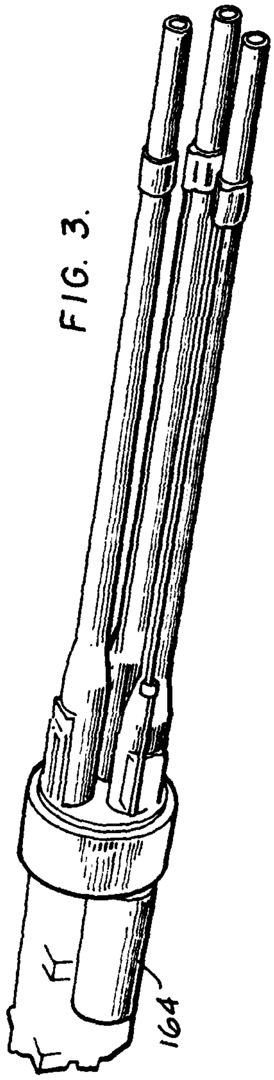


FIG. 3.

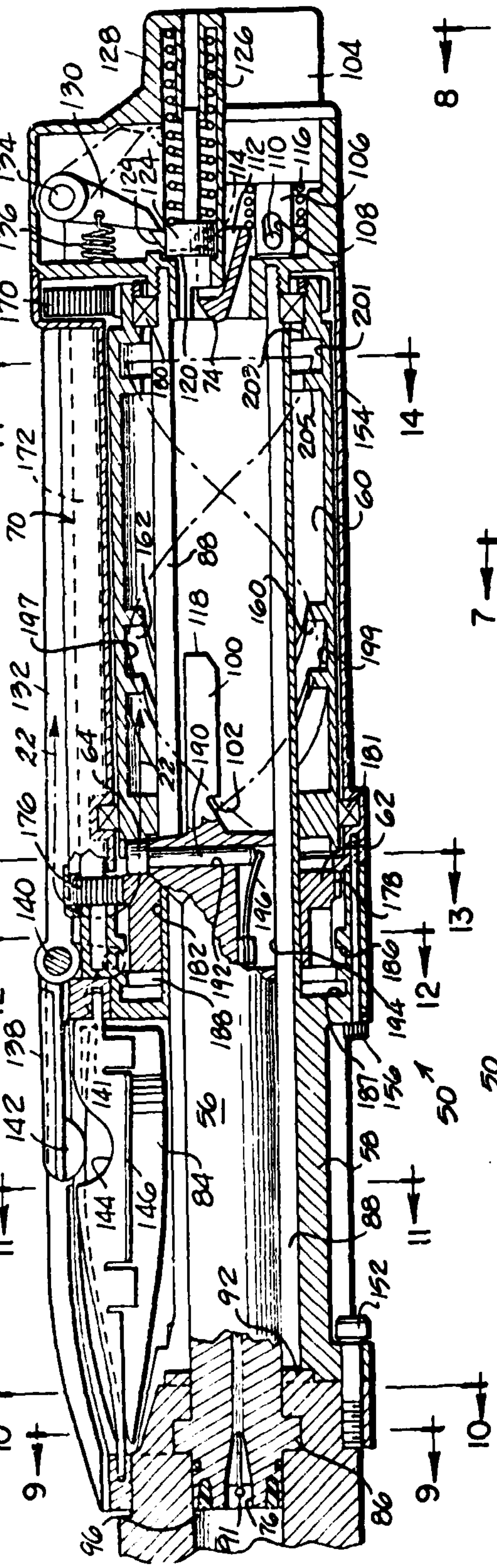


FIG. 6.

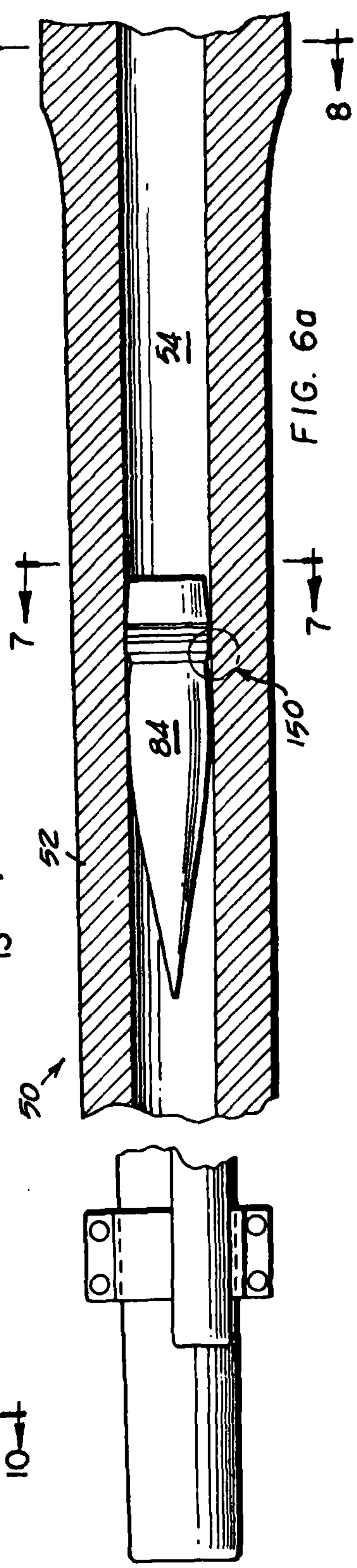


FIG. 6a

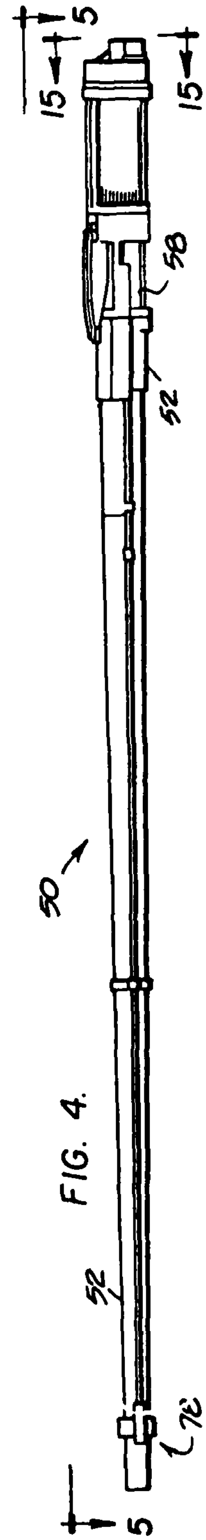


FIG. 4.

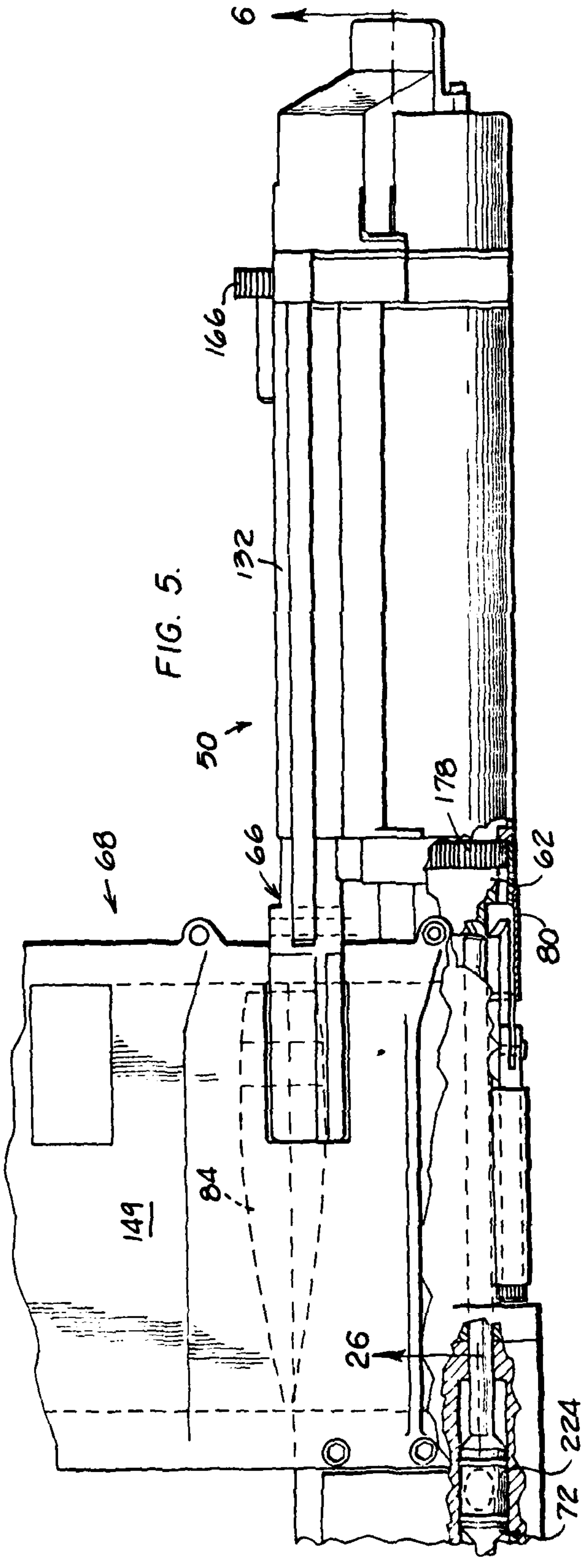

6
166
132
50
68
66
178
62
80
149
84
26
224
72

FIG. 5.

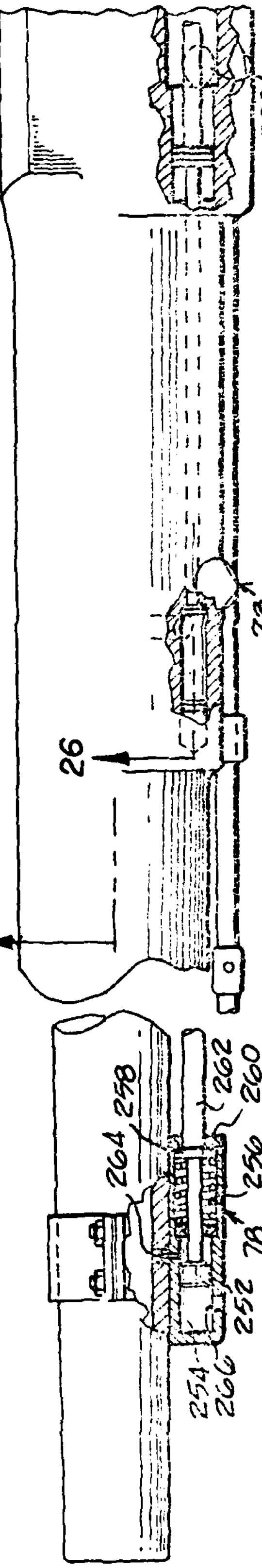

220'
73
26
6
262
260
258
264
256
78
252
254
266

FIG. 5a

FIG. 7.

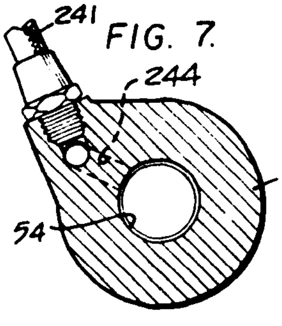


FIG. 8.

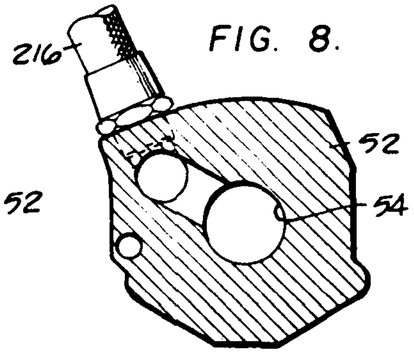


FIG. 9.

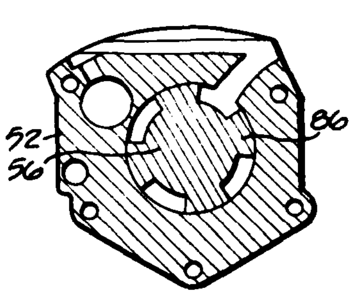


FIG. 10.

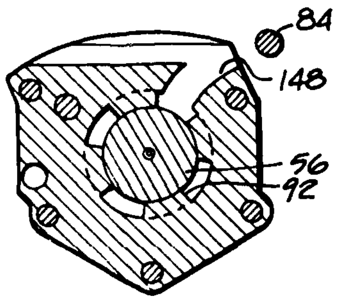


FIG. 11.

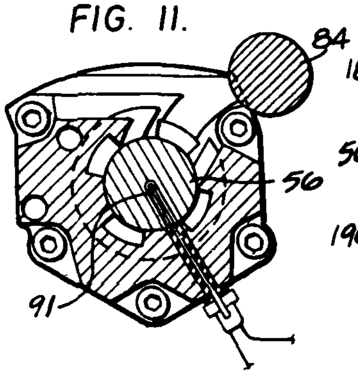
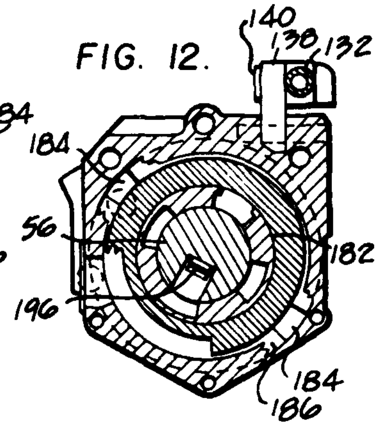


FIG. 12.



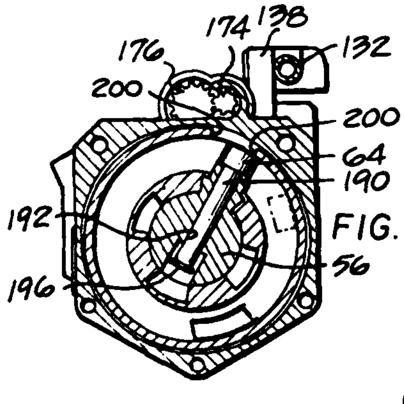


FIG. 13.

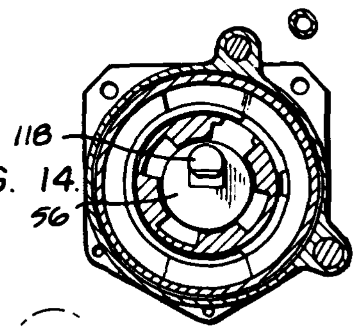


FIG. 14.

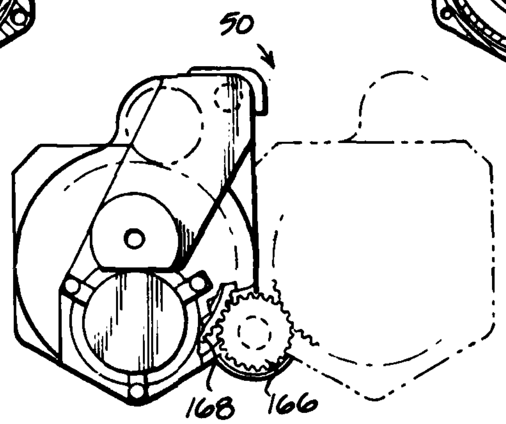


FIG. 15.

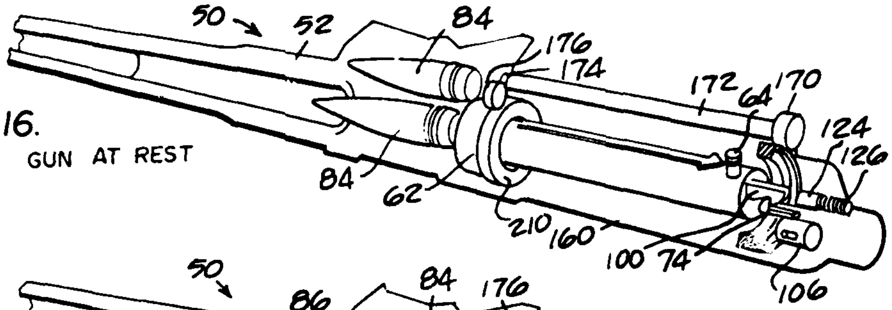


FIG. 16.
GUN AT REST

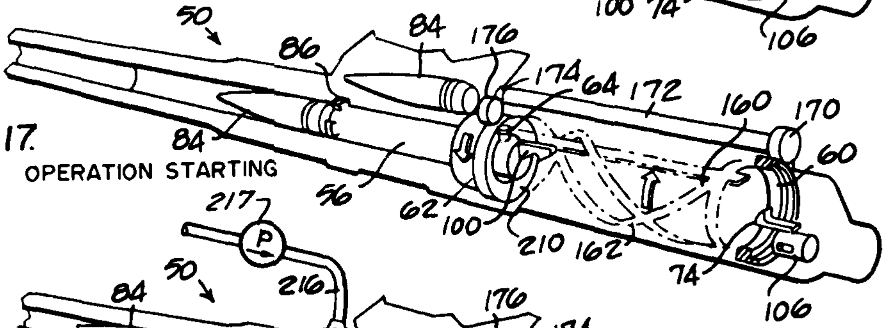


FIG. 17.
OPERATION STARTING

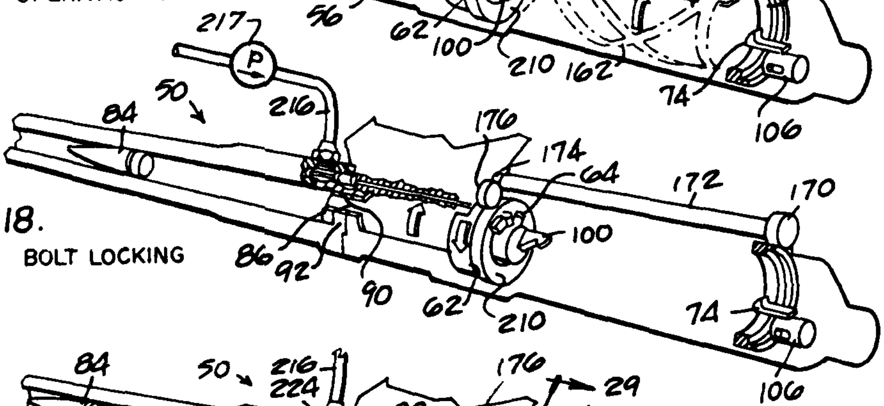


FIG. 18.
BOLT LOCKING

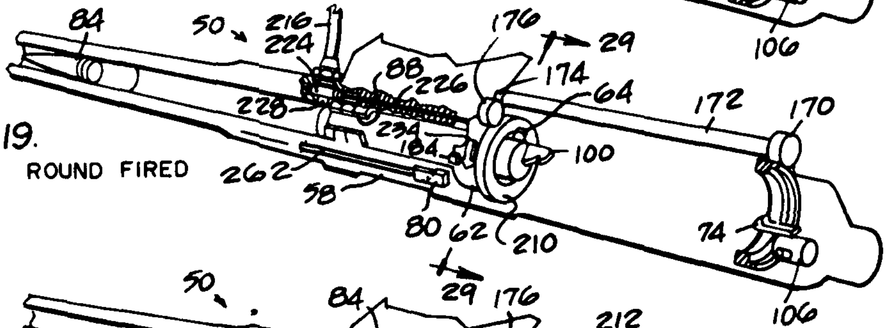


FIG. 19.
ROUND FIRED

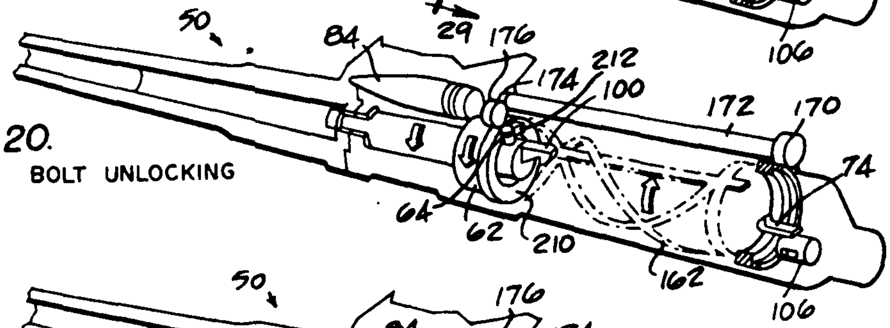


FIG. 20.
BOLT UNLOCKING

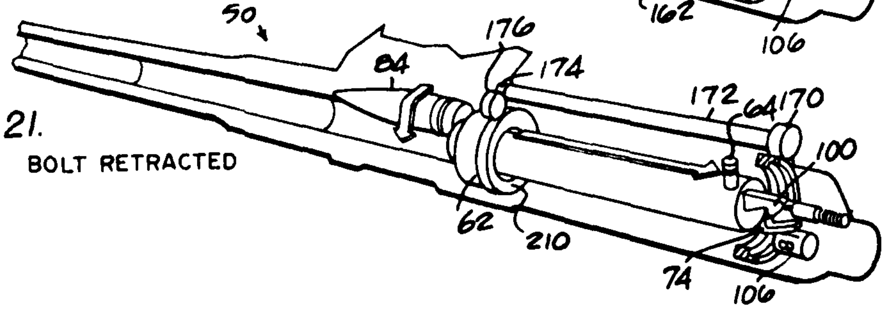
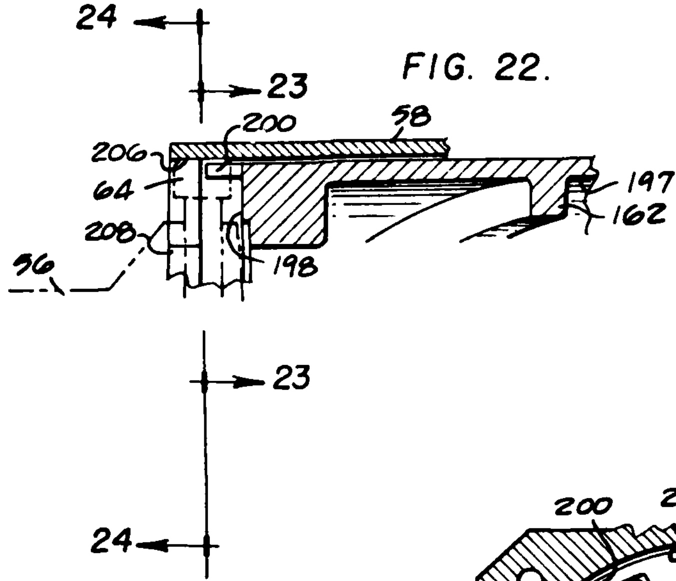


FIG. 21.
BOLT RETRACTED

FIG. 22.



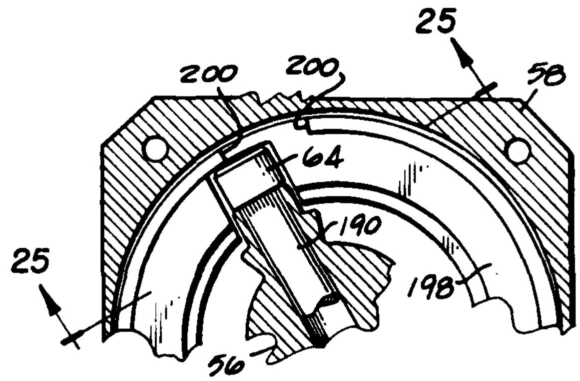


FIG. 23.

FIG. 24.

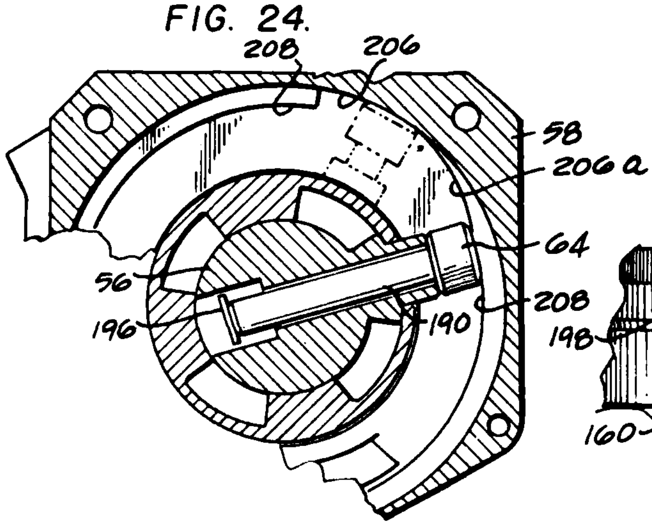


FIG. 25.

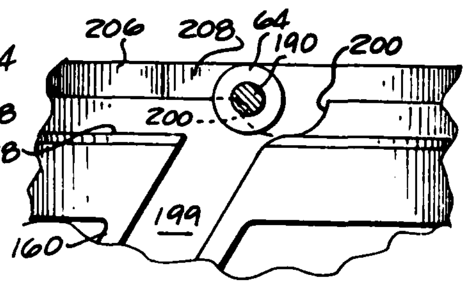


FIG. 26. FIRING POSITION

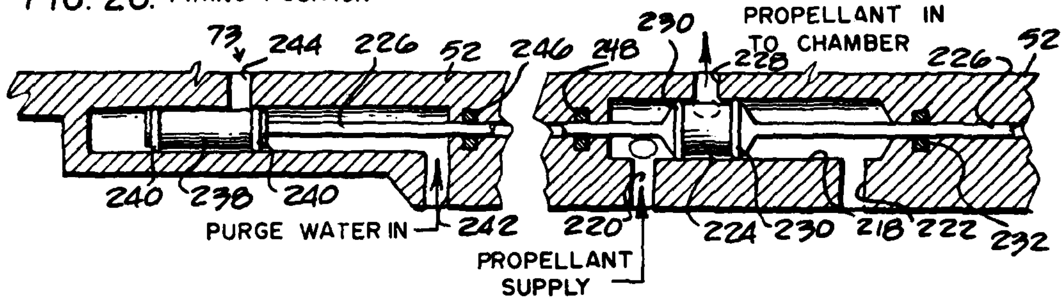


FIG. 27. PROPELLANT LOADING POSITION

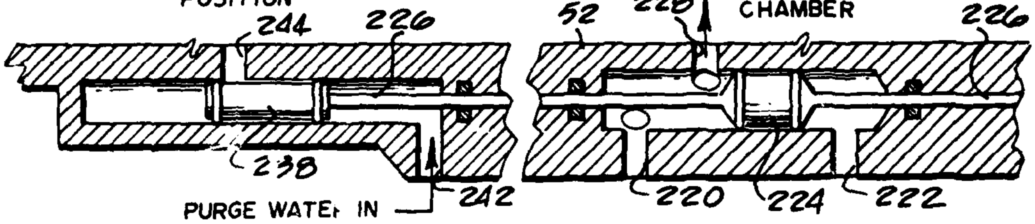
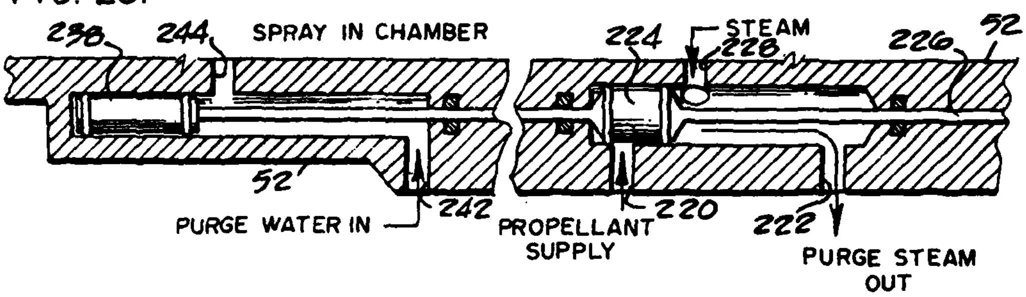


FIG. 28. EMERGENCY PURGE OR COMBUSTION CHAMBER COOLING



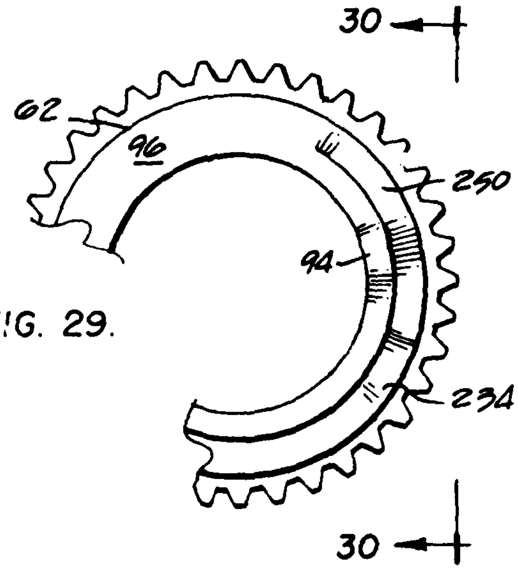


FIG. 29.

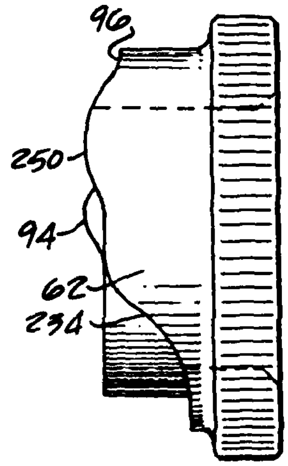


FIG. 30.

FIG. 31.

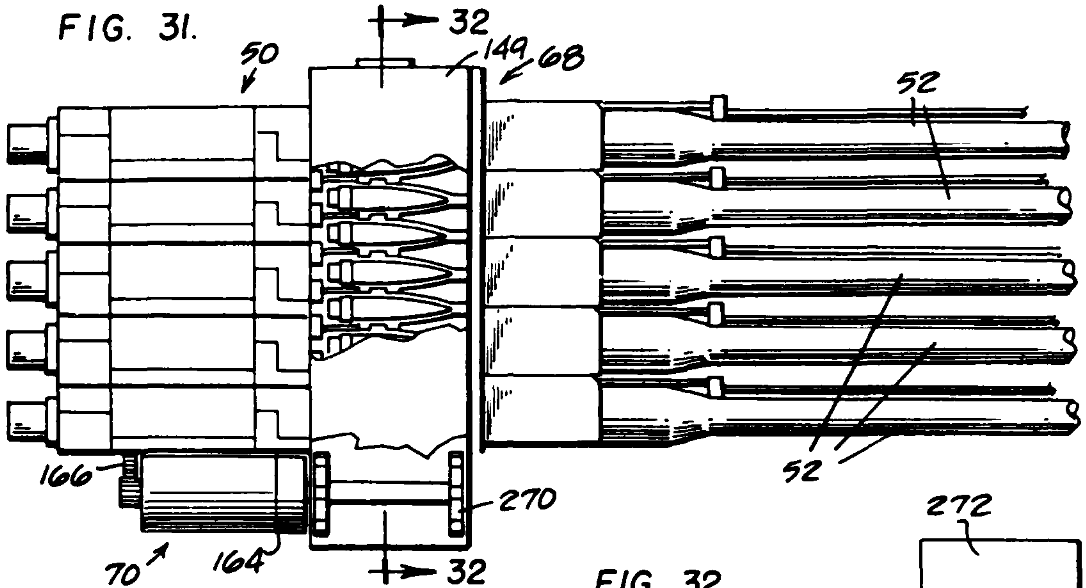


FIG. 32.

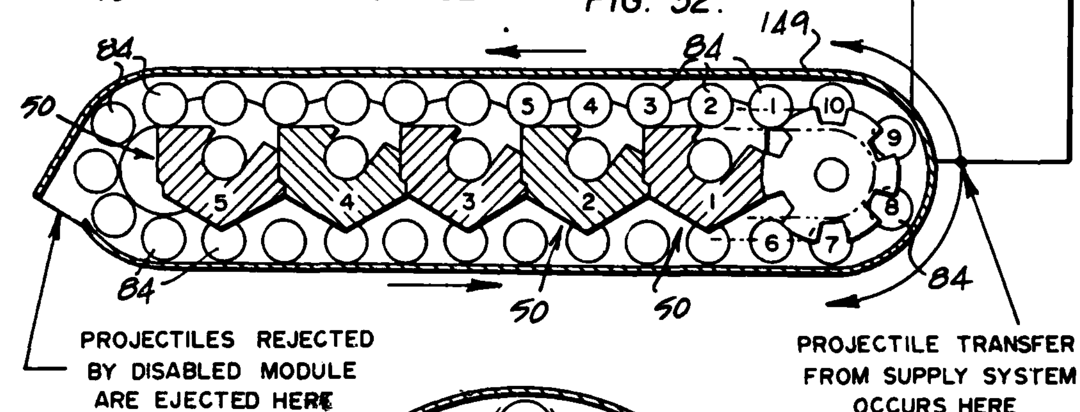
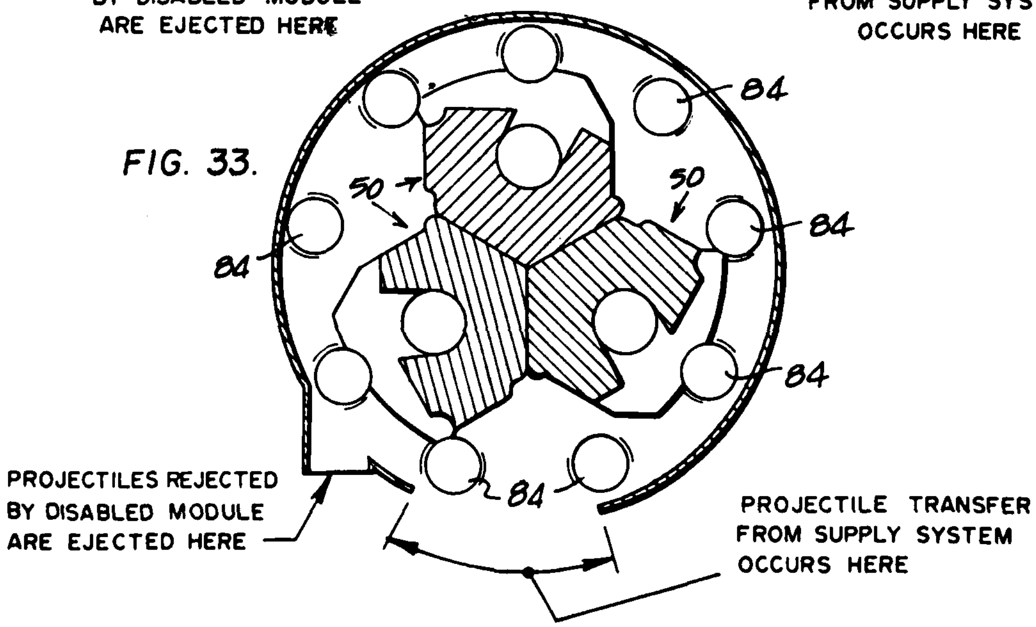


FIG. 33.



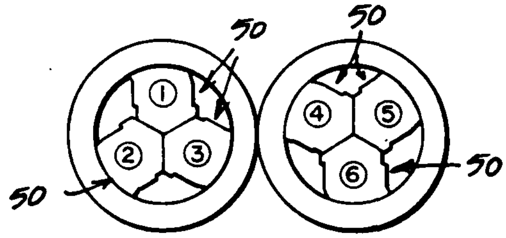


FIG. 34.

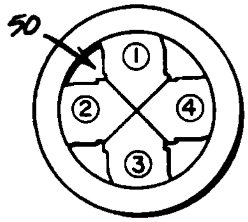


FIG. 35.

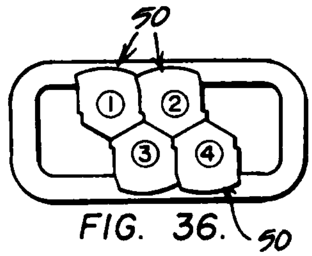


FIG. 36.

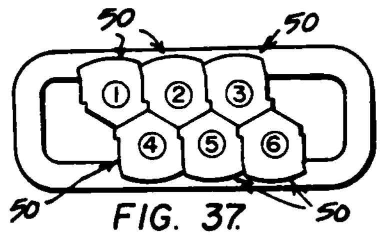


FIG. 37.

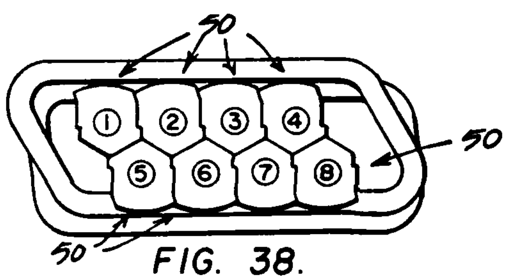


FIG. 38.

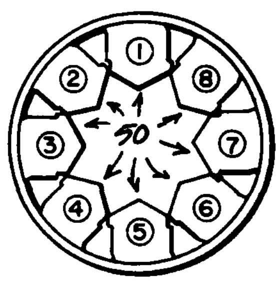


FIG. 39.

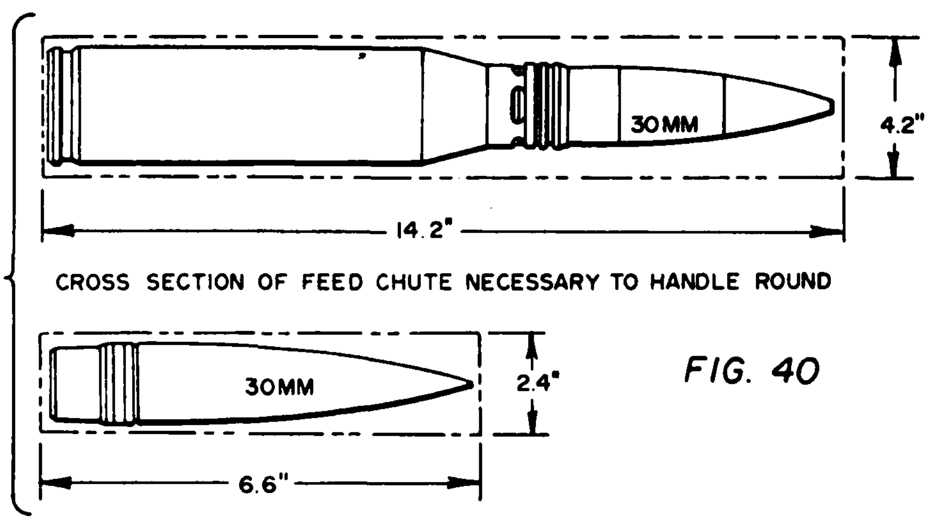


FIG. 40

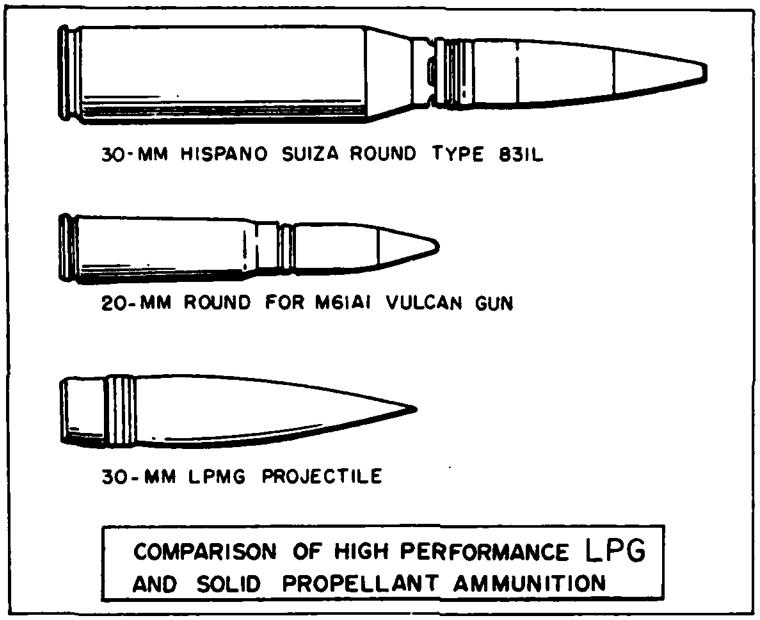


FIG. 41.

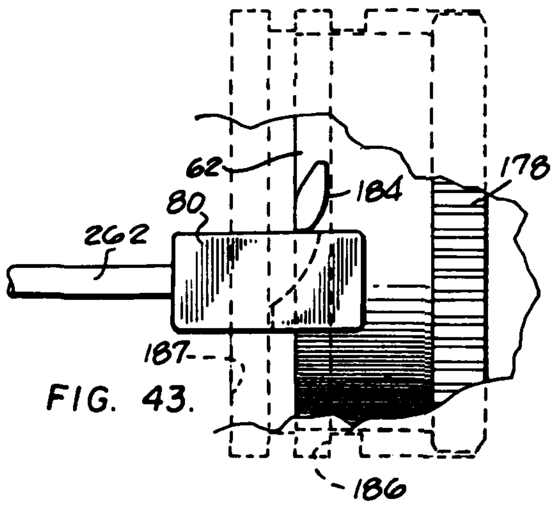


FIG. 43.

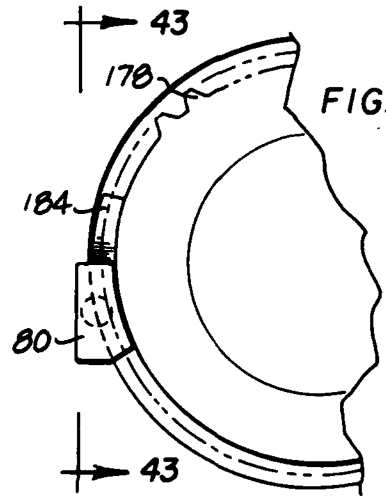


FIG. 42.

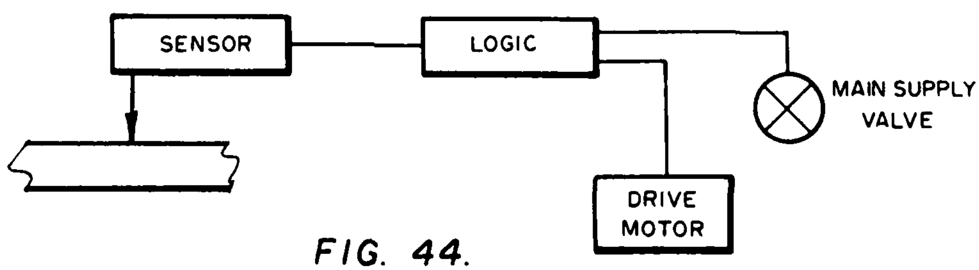


FIG. 44.

UNITED STATES PATENT OFFICE

CERTIFICATE OF CORRECTION

Patent No. 4,164,890 Dated August 21, 1979

Inventor(s) Lester C. Elmore et al

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

Column 2, line 46, "or single" should read --of single--.

Column 5, line 50-51, "cam follower in" should read --cam follower 64 in--

Column 6, line 34, "of an" should read --for an--.

Column 8, line 21, "zone" should read --cone--.

Column 9, line 6, "misfire. in" should read --misfire. In--; line 54, "0.8 1 turn" should read --0.8 turn--.

Column 10, line 4, "22 an 23" should read --22 and 23--.

Column 13, line 48, "Q=124,000" should read --Q=125,000--.

Signed and Sealed this

Thirteenth* Day of *November 1979

[SEAL]

Attest:

RUTH C. MASON,
Attesting Officer

LUTRELLE F. PARKER
Acting Commissioner of Patents and Trademarks

LIQUID PROPELLANT MODULAR GUN INCORPORATING DUAL CAM OPERATION AND INTERNAL WATER COOLING

This application is a division of parent application Ser. No. 616,822 filed Sept. 25, 1975, now U.S. Pat. No. 4,062,266, and entitled "Liquid Propellant Modular Gun Incorporating Dual Cam Operation and Internal Water Cooling" and claims the benefit of the filing date of the parent application.

BACKGROUND OF THE INVENTION

This invention relates to a liquid propellant gun of the kind in which liquid propellant is burned in a combustion chamber to fire a projectile from the gun. It relates particularly to a cam operated, externally driven, liquid propellant gun having a slim profile so that a plurality of single barrel gun modules can be conveniently clustered in a variety of configurations. The present invention also relates particularly to an internal water cooling arrangement which injects a small quantity of water into the combustion chamber for cooling by internal vaporization after the firing of each round and which also serves to fill the combustion chamber with water and to purge prr-pellant from the combustion chamber in the event of a misfire.

The present invention has particular utility for high performance, high rate of fire guns in the 20 to 35mm size. The present invention is not, however, limited to guns of this size.

The existing weapons used by the armed services use solid propellant cartridges. These existing weapons carry the solid propellant in cases, and the cases form a substantial part of the overall weight and overall size of the cartridge. This in itself imposes serious drawbacks and limitations on the installation and use of such weapons, because the projectile feed mechanism and related storage facilities must be large enough and strong enough to store and transport not only the projectile itself but also the related solid propellant and case.

Solid propellants have a further inherent disadvantage because of the fact that solid propellants characteristically develop a high peak temperature. In many gun installations it is necessary to fire long bursts in multiple engagements. Such projected firing schedules produce severe thermal loads on the gun and often cause barrel errosion with the existing solid propellant weapons.

Automatic guns used in antiaircraft roles are a good example of guns subjected to severe firing schedules. Long bursts are needed to achieve high cumulative kill probabilities. These gun systems must also engage multiple targets in rapid succession with little or no time between burst for adequate cooling. A severe barrel cooling problem results which is a primary factor in limiting system effectiveness. The reduced accuracy associated with premature barrel erosion can effectively destroy gun capability during a single engagement. The alternative is to increase the number of available mounts to achieve an acceptable firing schedule. This results in additional weight, complexity, cost and maintenance problems, and is therefore an unacceptable solution.

The problem has long been recognized in high performance, gun installations such as the U.S. Navy 40 mm Bofors automatic gun and the Oto Melara 76/62. In both cases a classic approach to barrel cooling has been taken, i.e. water jacketing of the exterior barrel surface.

However, even with exterior water jacketing, the heat transfer rate may be too limited for some applications.

The problems of severe thermal loads and barrel erosion also occur in drilling by cannon excavation. In cannon excavation the firing rate is relatively low but the duty cycle is sustained for long periods of time, and this produces severe thermal loads on the barrel.

It is one important object of the present invention to provide a more effective means for barrel cooling. This object is achieved in the present invention by internal water cooling. The way in which the internal water cooling is incorporated in a liquid propellant gun of the present invention also permits the mechanism for injecting the water for cooling to be used as a water purge system for purging the combustion chamber of liquid propellant in the event of a misfire, and this system and mode of operation constitutes another, specific object of the present invention. The internal water cooling system will be reviewed in more detail below in the Summary of the Invention and in the Detailed Description of the Preferred Embodiments of the present invention. At this point the applicants would like to point out that, because the water does impinge directly on the heated gun bore surfaces in the present invention, high heat transfer rates are realized and the effectiveness of the internal water cooling permits significant increase in burst length and frequency in automatic guns. It also permits a significant increase in length of the duty cycle in such applications as drilling by cannon excavation.

There are a number of recognized technical objectives for high performance guns. In general, these include: (1) increased velocity and rate of fire; (2) lower gun and ammunition weight; (3) improved interior and exterior ballistic performance; (4) decreased erosion, flash and smoke; (5) reduced recoil loads; (6) elimination of cases, links and sabots; (7) improved reliability and safety; and (8) versatility—application to a wide range or requirements.

In addition to these general improvements, the following characteristics are recognized as being factors lacking in the prior art and needed to enhance the applicability of future gun systems as compared to the prior art: (1) a gun of minimum cross section to assure maximum versatility of installation on shipboard, vehicle and aircraft mounts; (2) an envelope that will assure retrofit capability or single or multibarrel high performance 30 or 35 mm liquid propellant guns in existing 20 mm installations; (3) a mechanism design capable of employing high density, low drag projectiles currently in the inventory or in an advanced stage of development; (4) at the 30/35 mm scale—utilization of existing projectile designs (with only minor modifications) to eliminate immediate requirements for development of new projectiles, and muzzle velocities in excess of **4000** ft. per second employing high sectional density projectiles to provide adequate standoff, short time of flight, and high projectile payload; (5) a gun mechanism construction adaptable to operation at higher muzzle velocities when adequate projectiles are available; (6) stationary barrel construction with rotating cam feed mechanism to provide significant reduction in gun drive power requirements and quicker acceleration to full firing rate; (7) simplified gun harmonization at all firing rates by elimination of tangential projectile velocity components associated with rotating barrel systems.

A further requirement which has been placed on gun development in guns of this size range is that the gun must be applicable across the board to sea, air and

ground needs for the three services. These include (but are not limited to) small craft point defense, landing craft armament, retrofit of existing fixed wing aircraft and antiaircraft and antivehicle ground applications where rate of fire and configuration constraints vary widely. Some missions require single barrel guns with relatively low, adjustable rates of fire (0 to 1000 rpm). Others involve multibarrel installations at intermediate rates of fire (2000 to 3000 rpm), and finally there are those which require very high rates of fire (4000 to 6000 rpm). It can be seen that this range of rate of fire indicates that automatic guns are needed from one to eight barrels.

Liquid propellant guns have a characteristic low peak temperature. Because a liquid propellant will ignite in the bulk mode, it can be ignited, as by an electrical spark device immersed in the liquid propellant, without the need to vaporize the propellant prior to ignition. Liquid propellants are high energy density liquids and can be burned in discrete pulses to produce high combustion pressures. Pulsed burning of a liquid propellant can produce combustion pressures in the range of 10,000 to 80,000 psi and even higher. The magnitude of the average combustion pressure in such pulsed burning can be controlled by the amount of expansion permitted. Higher average combustion pressures can be produced by permitting less expansion.

The liquid propellant gun can produce a flatter combustion chamber pressure-time characteristic than a solid propellant gun. Hence, performance equivalent to a solid propellant gun can be obtained at lower pressure. High cyclic rates of fire are possible with a liquid propellant gun. Because the propellant is a liquid, the propellant can be easily pumped to the firing chamber from a storage area remote from the gun itself. This permits flexibility of installation. Because the cartridge feeding system of the liquid propellant gun carries only the projectile itself, the projectile feed system can be simplified and can be made considerably lighter in weight than for a conventional gun. Or, a considerably larger projectile size and weight can be used for higher performance without having to increase the size of the projectile feed mechanism. This is especially important in permitting larger bore liquid propellant guns to be incorporated in retrofit installations as replacements for existing smaller bore solid propellant guns.

Liquid propellant guns also permit slim profiles which provide desirable configuration versatility. Because the liquid propellant gun permits a low profile, clean exterior design, an individual liquid propellant gun module or a modular grouping of liquid propellant gun modules can be installed in locations that would not accomodate a conventional gun.

It is another important object of the present invention to incorporate the inherent advantages of a liquid propellant gun in a modular gun of the kind incorporating a drive cam and a control cam.

SUMMARY OF THE INVENTION

The liquid propellant gun of the present invention is a cam operated, externally driven gun constructed in modular form. It has a slim profile, and the operational features of the gun are arranged so that the gun can be readily incorporated in a variety of modular clusters, such as flat pack groupings and circular groupings.

The gun barrel is stationary and all combustion chamber pressure loads on the bolt are carried through the barrel rather than being carried through the receiver with the result that the receiver can be made quite light.

The gun incorporates two cams, a drive cam and a control cam.

The drive cam reciprocates the bolt back and forth between the rearward, projectile loading position and a forward, projectile firing position. The drive cam is a hollow cylindrical member having two spiral cam tracks formed on the inside of the drive cam. The first spiral cam track engages a cam follower on the bolt to drive the bolt forward, and the other spiral cam track engages the cam follower to drive the bolt rearward as the drive cam is rotated about the axis of reciprocation of the bolt.

The control cam is located at the front end of the drive cam, and the control cam is also an annular member which is rotated about the axis of the bolt. The control cam controls the injection of the liquid propellant into the combustion chamber and also controls the igniter for igniting the propellant.

The drive cam is rotated faster than the control cam and has dwell or rest areas at each end of the drive cam to provide the time intervals for the projectile loading at one end and the propellant injection and firing at the other end of the bolt's reciprocation.

The drive cam rotates the bolt in one direction at the end of its forward travel to lock the bolt to the barrel, and the control cam rotates the bolt in the opposite direction after firing to unlock the bolt from the barrel.

The axial sliding movement of the reciprocating bolt is guided by lugs on the bolt which interfit in slots in the barrel extension or receiver of the gun.

The cam follower of the bolt is mounted for a limited amount of radial movement with respect to the bolt to accomodate, by outward movement, the bolt rotation required to lock the bolt and, by inward movement, the required dwell at the forward end of the bolt travel. The barrel extension has a cam surface that coacts with the cam follower and a dwell area at the forward end of the drive cam to provide the required dwell in this part of the cycle of operation of the gun. The control can unlocks the bolt and returns the cam follower to the rearward, spiral drive cam track at the proper time.

The drive cam and the control cam are driven in synchronism by interconnected gearing, and the drive cams of adjacent gun modules are interconnected by idler gears for transferring drive from one module to the next.

The gun of the present invention incorporates a water cooling arrangement in which the control cam causes a small amount of water to be injected into the combustion chamber after the firing of each round. The injected water is vaporized and converted to steam as it contacts the hot combustion chamber structure, and this produces a highly effective cooling of the combustion chamber structure.

The water cooling valving is interconnected with the valving for the propellant injection in a manner such that the combustion chamber can be completely filled with water to purge the combustion chamber of propellant in the event of a misfire.

The gun incorporates misfire detection means which coact with the control can to completely disengage the control cam from the drive so that operation of the gun module is stopped in the event of a misfire.

Liquid propellant gun apparatus and methods which incorporate the structure and techniques described

above and which are effective to function as described above constitute specific objects of this invention.

Other objects, advantages and features of our invention will become apparent from the following detailed description of preferred embodiments taken with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is an isometric view of a liquid propellant gun module constructed in accordance with one embodiment of the present invention;

FIG. 2 is an isometric view showing three of the gun modules of FIG. 1 grouped in a flat pack cluster;

FIG. 3 is an isometric view showing three of the gun modules of FIG. 1 grouped in a circular cluster;

FIG. 4 is a side elevation view of the gun module shown in FIG. 1;

FIG. 5 is an enlarged top plan view of the gun module taken along the line and in the direction indicated by the arrows 5—5 in FIG. 4. In FIG. 5 some parts are partly broken away to show details of construction and FIG. 5a is a continuation of the left hand end of FIG. 5;

FIG. 6 is a side elevation view in cross section taken generally along the line and in the direction taken by arrows 6—6 in FIG. 5 and FIG. 5a. FIG. 6a is a continuation of the left hand end of FIG. 6. The cam follower 64 is shown rotated 30° in FIG. 6 for better illustrating its operation. See FIG. 13 for the true position of this cam follower;

FIGS. 7-14 are end elevation views in cross section taken along the lines and in the directions indicated by the correspondingly numbered arrows in FIG. 6;

FIG. 15 is an end elevation view taken along the line and in the direction indicated by the arrows 15—15 in FIG. 4;

FIGS. 16-21 are isometric views showing the disposition of certain parts of the gun in the various phases of operation indicated by the legends in these figures;

FIG. 22 is a fragmentary, enlarged view of the part of the structure shown encircled by the arrows 22—22 in FIG. 6. In FIG. 22 as in FIG. 6, the cam follower is shown rotated 30° from its actual position illustrated in FIG. 13;

FIG. 23 is a fragmentary, enlarged end elevation view taken along the line and in the direction indicated by the arrows 23—23 in FIG. 22, but with the cam follower at the actual inclination illustrated in FIG. 13;

FIG. 24 is a fragmentary, enlarged end elevation view taken along the line and in the direction indicated by the arrows 24—24 in FIG. 22 showing the cam follower in the unlocked position in phantom outline and in a locked position in bold outline;

FIG. 25 is a fragmentary, enlarged bottom plan view taken along the line and in the direction indicated by the arrows 25—25 in FIG. 23;

FIG. 26 is a fragmentary enlarged side elevation view taken along the line and in the direction indicated by the arrows 26—26 in FIG. 5. FIG. 26 shows the positions of the water injection and the propellant injection control valves during firing of the gun;

FIG. 27 is a fragmentary enlarged side elevation view like FIG. 26 but showing the positions of the water injection and propellant injection control valves during propellant loading;

FIG. 28 is a view like FIGS. 26 and 27 but showing the positions of the water injection and propellant injection control valves during either the combustion chamber cooling or the emergency purge operations;

FIG. 29 is a fragmentary, enlarged view of the front face of the control cam and is taken generally along the line and in the direction indicated by the arrows 29—29 in FIG. 19. FIG. 29 shows the recess in the control cam for the control of the propellant injection, the projection on the control cam for the water injection and a projection on the control cam for controlling the operation of the igniter;

FIG. 30 is a fragmentary enlarged plan view taken generally along the line and in the direction indicated by the arrows 30—30 in FIG. 29;

FIG. 31 is a top plan view showing five gun modules assembled in a flat pack cluster together with a drive motor for the gun modules and the projectile feed system;

FIG. 32 is an end elevation view taken generally along the line and in the direction indicated by the arrows 32—32 in FIG. 31. FIG. 32 shows the feeding of specific projectiles in the endless conveyor belt to related gun modules;

FIG. 33 is an end elevation view like FIG. 32 but showing the projectile feed system for three gun modules assembled in a circular cluster;

FIGS. 34-39 illustrate different cluster configurations for the modular gun of the present invention and illustrate how projectile feed systems are associated with these different cluster configurations;

FIG. 40 is a plan view showing a size comparison for high performance 30 mm liquid and solid propellant rounds of ammunition and also illustrates the relative feed chute sizes required;

FIG. 41 is a top plan view showing a size comparison of a 30 mm liquid propellant projectile, a conventional solid propellant 20 mm round of an M61 Vulcan gun and a conventional solid propellant round for a 30 mm Hispan Suiza round type 831L. FIG. 41 illustrates how a 30 mm liquid propellant round is approximately the same overall length as a conventional solid propellant 20 mm round and how it is therefore capable of being substituted in conventional projectile feed systems for smaller 20 mm solid propellant rounds with a minimum of retrofit modifications;

FIG. 42 is a fragmentary and elevation view showing details of the misfire switch and control cam shifting lug;

FIG. 43 is a fragmentary side elevation view taken along the line and in the direction indicated by the arrows 43—43 in FIG. 42;

FIG. 44 is a schematic view of a pressure sensing interlock system for stopping operation of a gun module in the event of a drop in propellant feed pressure.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

A liquid propellant gun module constructed in accordance with one embodiment of the present invention is indicated generally by the reference numeral 50 in FIGS. 1, 4, 5, 6 and 16 through 21.

The gun module 50 includes a barrel 52, a combustion chamber 54, a bolt 56, a barrel extension or receiver 58, a drive cam 60, a control cam 62, a cam follower 64, a projectile loading mechanism 66 for loading projectiles from a projectile feeding mechanism 68, a drive mechanism 70, propellant injection means 72, water coolant and purge means 73, a bolt sear 74, an igniter 76, misfire detection means 78 and a misfire switch 80, all as indicated generally by these reference numerals in FIGS. 5 and 6 and in other FIGS. of the drawings.

The gun module **50** illustrated in the drawings use a liquid monopropellant (i.e. a liquid propellant that contains both a fuel and an oxidizer) in the combustion chamber **54** for firing a projectile **84**. It should be noted, however, that many of the features of the present invention are not limited to a modular gun or to a gun using a monopropellant, as will become more apparent from the description to follow.

The bolt **56** is reciprocable back and forth between a rearward, projectile loading position (see FIG. **16**) and a forward, projectile firing position (see FIGS. **18, 19** and **20**).

The bolt is guided in this reciprocating movement by lugs **86** (see FIG. **17** and FIG. **9**) which slide within guide slots **88** (see FIGS. **19** and **11**) in the barrel extension **58** and guide slots **90** (see FIG. **18** and FIG. **10**) extending through locking lugs **92** at the rear end of the barrel **52**.

The igniter **76** is located in the front face of the bolt **56** and comprises an electrode **91** (see FIG. **6** and FIG. **11**) which is energized when a cam follower (not illustrated) is displaced by a projection **94** on a forward control face **96** of the control cam **62** (see FIGS. **29** and **30**). Energization of the electrode **91** produces electrical energy which ignites the liquid propellant in the combustion chamber **54** to fire the projectile **84** out of the barrel **52**. Ignition can also be accomplished by compression ignition or by injecting a chemical into the propellant.

The forward face of the bolt **56** has a seal **96** as best illustrated in FIG. **6**.

The rear end of the bolt **56** has a bolt extension **100** which coacts with the projectile loading mechanism **68** to snap a projectile out of a spring clip carrier in the projectile feed mechanism **66** (in a way to be described in more detail below) when the bolt is moved to the rearward, projectile loading position.

The bolt extension **100** also has a detent **102** which is engaged by the pawl of the sear **74** to hold the bolt in the rearward position when the gun trigger is off and a sear solenoid **104** is deenergized.

A sear actuating rod **106** is connected to the rear solenoid **104** and has a slot **108** (see FIG. **6**). A pin **110** rides in the slot **108** at the lower end of the pivot arm and is connected at the lower end of the pivot arm **112** of the sear **74**. The arm **112** pivots about a sear pivot **114** which straddles the spring cavity. As illustrated in FIG. **6**, a spring **116** normally biases the sear pawl **74** toward a bolt retaining position, but energization of the sear solenoid **104** rotates the pawl **74** downward to the bolt releasing position (best illustrated in FIG. **21**).

The end face **118** of the bolt extension **100** is engageable with a face **120** of a spring backed part **124** which actuates the projectile loading mechanism **66**. The back face of the part **124** provides a spring seat for one end of a bolt return spring **126**. (See FIG. **6**). The other end of the bolt return spring **126** is seated against an inner face of a rear cover **128**.

The part **124** has an upwardly projecting flange **129** which is engageable with an actuator level **130** of the projectile loading mechanism **66**. The upper end of the actuator level **130** is connected to a push rod **132** by a pin joint connection **134**, and a spring **136** maintains the lower end of the actuator lever **130** in engagement with the upwardly extending flange **129**.

The front end of the push rod **132** is connected to a bellcrank loading lever **138** by a pin joint connection **140**. The downwardly extending arm of the bellcrank projectile loading lever **138** is pivotally connected to the barrel extension **58** by a loading lever pivot **141**.

The forwardly extending arm of the projectile loading lever **138** has a lower end **142** which is positioned over an upper recess **144** in a spring clip carrier **146** for a projectile **84**. This projectile is aligned with the upper end of a projectile receiving passageway **148** in the barrel extension **58** (see FIGS. **10** and **11**).

Engagement of the bolt extension **100** with the rod **120** moves the lower end of the actuator lever **130** about the pivot provided by the connection to the spring **136** to shift the rod **132** forward. This pivots the bellcrank **138** about the pivot **141** and snaps a projectile **84** out of the spring clip carrier **146** of the endless conveyor belt **149** (see FIG. **32**) of the projectile feed mechanism **68**.

The projectile drops into the passageway **148** and into the bore in the barrel extension in front of the bolt **56**. Forward movement of the bolt **56** then pushes the projectile up into the barrel **54**, and the projectile **84** is then pumped forward (to the position illustrated in FIG. **6**) against the forcing zone **150** by the liquid propellant injected into the combustion chamber. This will be described in greater detail below.

The barrel **52** is connected to the barrel extension **58** by cap screws **152** (see FIG. **6**).

A cam cover **154** is connected to the barrel extension **58** by cap screws **156** as also shown in FIG. **6**.

The drive cam **60** has two internal, spiral shaped, cam paths **160** and **162** which are engageable with the cam follower **64** for reciprocating the bolt **56** forward and backward during operation of the gun. The spiral cam track **160** drives the bolt **56** forward, and the spiral cam track **162** drives the bolt **56** rearward.

The drive cam **60** is axially elongated so that the cam angles are not too high, and the drive cam is rotated faster than the control cam **62**.

As best shown in FIGS. **1-3** and **31**, the drive system **70** includes a drive motor **164**. The drive motor **164** rotates an idler gear **166**, and the idler gear **166** is engaged with a gear **168** formed on the outer diameter of the drive cam **60** at the rear end of the drive cam **60**.

FIG. **15** illustrates how this same idler gear **166** is used to transfer the drive from one module to an adjacent module in a cluster arrangement.

The drive to the control cam **62** is provided by a jack shaft take off gear **170**, a jack shaft **172**, a jack shaft pinion gear **174**, an idler gear **176** and a gear **178** formed on the outer diameter of the control cam **62** (as best illustrated in FIGS. **6** and **16** through **21**). The control cam **62** is therefore rotated in a direction opposite from that of the drive cam **60**, as indicated by the arrows in FIG. **17**.

In a particular embodiment of the present invention the gear ratios are such that the drive cam **60** is rotated four times as fast as the control cam **62**.

The drive cam **60** is mounted for rotation on the barrel extension **58** by bearings **180** at the rear end of the drive cam and **181** at the forward end of the drive cam (see FIG. **6**).

The control cam **62** is mounted for rotation on a surface **182** of the barrel extension **58** and is normally retained in a fixed axial position with respect to the barrel extension **58** by two radially projecting cam lobes **184** on the outer periphery of the control cam **62** (see FIG. **12**). The lobes **184** travel in an annular groove **186** in the barrel extension **58**. In normal operation of the gun the lobes **184** travel in the groove **186** and the control cam **62** is maintained in the fixed axial position

illustrated in FIG. 6 with the gear **178** engaged with the gear **176**. However, the barrel extension **58** has a relieved space **188** in front of the control cam which permits the control cam to be shifted axially forward and disengaged from the drive connection with the idler gear **176** in the event of a misfire. in this condition of operation as illustrated in FIG. **43** and as will be described in more detail below, the misfire switch **80** engages one of the cam lobes **184** to move the control cam **62** forward. The cam lobe that engages the misfire switch is diverted into a dead end side track **187**, and the other lobe **184** enters a relieved area.

As best illustrated in FIGS. **6** and **13**, the cam follower **64** is a cylindrical element at the outer end of a rod **190**. The rod **190** is mounted for axial movement in a radially extending bore **192** at the back end of the bolt **56**. The underside of the bolt **56** has a recessed groove **194**, and a leaf spring **196** is mounted in the groove **194** so as to engage the lower end of the rod **190**. The spring **196** biases the cam follower radially outwardly and into engagement with associated surfaces on the drive cam **60** and, during part of the time that the bolt **56** is in its forward projectile firing position, with associated large diameter surface **206** and smaller diameter surface **208** on the barrel extension **58**. See FIG. **24**. This will be described in more detail below.

During forward driving movement of the bolt **56**, the outer surface of the cam follower **64** is engaged with a surface **199** of the forward driving cam track **160**. See FIGS. **6**, **17** and **22**. During rearward driving of the bolt **56**, the outer surface of the cam follower **64** is engaged with a surface **197** of the spiral cam track **162**.

The drive cam **60** has dwell or rest areas at the front and rear ends of the drive cam. The dwell areas provide turnarounds at each end of the bi-directional drive cam.

The rear dwell area includes a surface **201** which is bounded by a rear, radially inwardly extending flange **203** and a forward, inwardly extending flange **205**. See FIG. **6**. This dwell area at the rear of the drive cam holds the bolt **56** in a retracted position from the time that the cam follower **64** leaves the return cam track **162** until the drive cam is rotated to a position in which an opening in the forward flange **205** permits the bolt return spring **126** and part **124** to shove the cam follower **64** into the forward drive cam track **160**.

In a particular embodiment of the present invention (having the 4 to 1 ratio of drive cam revolutions to control cam revolutions for each cycle of operation as noted above), the cam follower **64** rests at the rear dwell area of turnaround for 0.6 turn of the drive cam **60**. The forward drive spiral **160** moves the cam follower forward for 0.8 turn of the drive cam **60**. The cam follower moves rearward for 0.8 l **turn of the drive can and rests at a forward dwell area for approximately** 1.8 turns of the drive cam **60**.

When the bolt **56** reaches the forward end of its travel, it must be rotated 45° (as illustrated in FIG. **13**) to lock the lugs **86** on the bolt in front of the lugs **92** of the barrel **52** (see FIG. **18**).

The construction of the forward end of the drive cam **60** and related structure of the barrel extension **58** and back face of the control cam **62** are best illustrated in the enlarged fragmentary view of FIG. **22**.

As best illustrated in FIG. **22**, when the cam follower **64** leaves the forward end of the forward drive cam track **160**, the back side of the cam follower **64** is positioned in a forward dwell area **198** so that continued rotation of the drive cam **60** cannot produce any continued forward movement of the bolt **56**.

The drive cam **60** does, however, have a slot **200** (see FIGS. **22** an **23**) located at the forward, outlet end of the forward cam track **160** so that the spring **196** (see FIG. **6**) shoves the rear half of the cam follower **64** outward and into this slot **200** as soon as the forward reciprocation of the bolt has been completed. The rotation of the drive cam **60** in the clockwise direction indicated by the arrow in FIG. **17** then rotates the cam follower and bolt 45° to the locking position illustrated in FIG. **18**.

At the same time that the back half of the cam follower **64** moves into the slot **200**, the front half of the cam follower **64** engages the large diameter surface **206** (see FIG. **24**) of the barrel extension **55**. This surface **206** has a ramp **206a** which decreases in diameter, as the bolt is rotated 45° to the locked position, until the diameter is the same as that of the surface **208**. This ramp **206a** pushes the cam follower **64** downward from the outwardly extended position shown in phantom outline in FIG. **24** to the retracted position shown in solid outline in FIG. **24**.

The surface **208** thereafter engages the top of the front half of the cam follower **64** to retain the cam follower **64** in the retracted position and within the groove **198** of the drive cam **60** until the firing of the projectile from the combustion chamber **54** has been completed and the bolt **56** is ready to be rotated back 45° to an unlocked position and then retracted to the projectile loading position by engagement of the cam follower **64** within the rear drive cam track **162**.

While the cam follower **64** is retained in the retracted position illustrated in FIG. **24** by the stationary engagement of the cam follower **64** with the surface **208** at the end of the ramp **206**, the drive cam **60** is of course continuing to rotate with respect to the cam follower **64** with the back half of the cam follower **64** engaged in the relieved area of the recessed face **198**. At the same time the rear face **210** of the control cam **62** is rotating counter clockwise with respect to the cam follower **64**, as illustrated by the arrows in FIGS. **18** and **19**.

The rear face **210** of the control cam has a bolt unlocking and return wedge **212** projecting outwardy from the rear face **210**. As this wedge rotates into engagement with the cam follower **64**, it first of all rotates the cam follower and bolt 45° counter clockwise (as viewed in FIG. **20**) to unlock the bolt by aligning the lugs **86** with the slots **90**. Continued rotation of the control cam **62** then moves the cam follower **64** axially to the rear and into the front inlet end of the rear drive cam track **162**, as this end of the cam track **162** opens to the front dwell area **198**. Continued rotation of the drive cam **60** then reciprocates the bolt **56** to a rearward, projectile loading bolt position.

The gun **50** as illustrated in the drawings uses a liquid monopropellant, i.e. a liquid propellant having both a fuel and an oxidizer. Mixtures of hydrazine, hydrazine nitrate and water are examples of monopropellants that may be used. However, propellants developed for torpedo application have physical, performance, handling and safety characteristics that are well suited for use in the present invention. This is understood since torpedo propellants must be compatible with the long duration, closed environment of a submarine where adverse characteristics from the standpoint of toxicity, handling or safety are completely intolerable. The liquid propellant is stored, either adjacent to the gun **50** or remotely, and is conducted to the propellant injection means **72** by a

flex conduit 216 as shown in FIGS. 18 and 19. The propellant supply pressure is supplied either by pump or by an accumulator subsystem (not illustrated). The accumulator is preferable from the standpoint of being effective in reducing pump volume requirements while meeting the peak flow rates necessary for burst fire. The propellant supply system includes a pressure sensing interlock system (see FIG. 44) which senses the propellant pressure by means of a sensor and stops operation of the complete group (row or cluster) of gun modules by closing a main propellant supply valve and stopping operation of the drive motor when the supply pressure drops below an established level. This prevents incomplete propellant filling.

The porting and valving arrangement for controlling the injection of liquid propellant into the combustion chamber 54 is best shown in FIGS. 5, 8, 18 and 26–28 of the drawings.

As best illustrated in FIG. 26, the sidewall of the barrel 52 has an axially extending bore 218 at one side of the combustion chamber 54, and the propellant conduit 216 is connected with a port 200 at one end of the bore. A port 222 connects the other end of the bore to drain.

A spool valve 224 is mounted for axial movement within the bore 218, and the control of the position of the spool valve 224 is provided by a valve control rod 226 which is connected to the valve spool 224 at one end. The other end of the rod 226 is engaged with the front face 96 (see FIG. 29) of the control cam 62 and acts as a cam follower.

A port 228 connects the axial bore 218 with the combustion chamber 54.

The valve spool 224 has annular seals 230 at each end of the spool and the rod 226 is sealed by a seal 232 as illustrated in FIG. 26.

The cam face 96 of the control cam 62 is formed with a recessed ramp 234 which controls the duration of the time period for injection of the liquid propellant through the ports 220 and 228. The control rod 226 is biased (by the propellant supply pressure) to the right (as viewed in FIG. 26) so that the cam follower end of the rod 226 is maintained in engagement with the face 96 of the rotating control cam 62.

In the firing position, the valve spool 224 is positioned by the control rod 226 to block off the port 228 (as illustrated in FIG. 26).

FIG. 27 illustrates the position of the valve spool 226 with respect to the port 228 when the recess 234 of the control cam 62 has been rotated to a position in which the control rod 226 first drops down into the recess 234. The valve spool 224 is shifted to the right in the bore 226 to open the port 228 for communication with the port 220, and the liquid propellant flows into the combustion chamber under the pressure of the propellant supply system. The pressure of the inflowing propellant pumps the projectile 84 forward to the position illustrated in FIG. 6a. The inclined ramp in the recess 234 pushes the control rod 226 leftward and back to the position illustrated in FIG. 26 as the cam follower end of the control rod 226 returns to the plane of the front face 96 of the control cam 62. The amount of liquid propellant injected is therefore determined by the pressure of the propellant supply system and the length and angular inclination of the recess 234.

As illustrated in FIG. 29, the front face 96 of the control cam 62 has a projection 94 which is engaged by a spring biased cam follower. The electrode 92 is energized as the igniter cam follower is actuated by the projection 94 following the filling of the combustion chamber 54 with the liquid propellant.

A very important feature of the present invention is the internal water cooling provided by the coolant injection means 73.

The coolant injection means 73 inject a small quantity of water directly into the firing chamber 54 between rounds. Since water impinges directly on the heated gun bore surfaces, high heat transfer rates are realized. The effectiveness of the internal water cooling permits a significant increase in burst length and frequency in the case of an automatic gun fired at high cyclic rates and permits a significant increase in the length of the duty cycle of guns used at lower cyclic rates such as in common excavation.

In a specific embodiment of the present invention water is used as the cooling liquid because it has a high heat of vaporization and is readily available. Other liquid coolants can of course be used, but the description to follow will be directed specifically toward the use of water as the coolant liquid.

One embodiment of the valve structure for accomplishing the internal water cooling is illustrated in FIGS. 5 and 26–28. As illustrated in these drawings, the wall of the gun barrel 52 has an axially extending bore 236. A valve spool 238 is mounted for reciprocation within the bore, and the valve spool has seals 240 at each end.

A water inlet port 242 is connected to one end of the bore 236 and a hose is attached to this port 242 to connect the port to a pressurized water supply system.

A port 244 connects the bore 236 to the combustion chamber 54.

The valve spool 238 is connected directly to the valve spool 224 through an extension of the rod 226 so that the water coolant valve spool 238 moves in unison with the propellant injection valve spool 224.

Seals 246 and 248 seal off the part of the rod 226 extending between the bores 236 and 218.

In the firing position of the valve spools (as illustrated in FIG. 26) the valve spool 236 blocks flow of water into the port 224 and flow of combustion gases out of the port 244.

Similarly, the water injection valve spool 238 is positioned in the propellant loading position illustrated in FIG. 27 to block flow through the port 244.

However, immediately after firing, the control cam 62 rotates to a position in which a projection 250 shifts the control rod 226 leftward (as viewed in FIG. 28) by an amount sufficient to open the port 244. This projection 250 permits a short time period for the injection of coolant water into the combustion chamber (through the passageway provided by the ports 242, the bore 236 and the port 244) before the cam follower end of the control rod 226 moves down off the projection 250 and back onto the plane of the face 96. This small amount of water is vaporized by the hot wall structure of the combustion chamber and turned to steam. During this water injection period, the port 228 may be maintained closed by the land 224 or, depending on the size of the projection 250, the port 228 may also be opened for venting of gas and steam from the combustion chamber (through the port 228 and the bore 218 and the vent port 222).

Thus, immediately after firing each round, the coolant injection means 73 are opened and a metered quantity of water is injected directly on the forward portion of the combustion chamber 54. The water spray is directed toward the combustion chamber surfaces of the

gun. The quantity of water is metered to insure that virtually all of it is converted to steam.

The next projectile **84**, in the process of being loaded and pumped forward in the chamber, pushes any steam and water remaining in the chamber ahead of the projectile into the barrel. After firing, the residuals are forced out of the barrel by the projectile as it traverses the bore.

If the distribution of the water vapor in the bore is assumed to be the same as the normal products of combustion of a liquid propellant, the weight of gas (vapor) being pushed out by the projectile is slightly less than that for a conventional solid propellant round. This results from the somewhat lower molecular weight of liquid propellant combustion products and that of the water vapor.

The internal water cooling is optimized to inject no more water than is vaporized. Hence, there is no penalty for acceleration inert mass. The water injected is controlled by the dwell of the surface **250** of the control cam **62**.

Heating and cooling of a gun barrel bore surface is highly transient. The analysis of the instantaneous heat transfer process is complex and methods for accurately determing the heat transfer coefficient controlling the process are not well established. However, the following example, based on average conditions, does illustrated the effectiveness of the internal water cooling.

Considering a 35 mm 4,000 ft/sec muzzle velocity liquid propellant gun, the significant characteristics are:

Projectile Weight—1.2 lb.

Muzzle Velocity—4,000 ft/sec.

Propellant Charge—1 lb.

Projectile Muzzle Kinetic Energy—298,000 ft.-lb.

Firing Rate—750 rounds per minute

Estimates of barrel heating per round are calculated using the criteria established by Corner[1] where the heat loss Q is:

$$Q = X\left(\tfrac{1}{2}W_1V^2\right)$$

W_1 = "Effective" Mass of the projectile

V = Muzzle velocity

$X \cong 0.3$ (maximum value)

[1] "Theory of the Interior Ballistics of Guns". J. Corner. Pg. 141. John Wiley & son.

For the characteristics of the 35 mm 4,000 ft/sec LPG, Q = 124,000 ft.-lb. (or 161 B.t.u.).

Gun barrel cooling is accomplished by direct water injection on the interior heated surfaces. Assuming initial water temperature to be 70° F., the heat absorption capability of the injected water (including specific heat and heat of vaporization) is approximately 1,110 B.t.u./lb. The quantity of water required for complete cooling after each round is then

$$= \frac{161 \text{ B.t.u./round}}{1110 \text{ B.t.u./lb.} H_2O} \text{ or } 146 \frac{\text{lb.} H_2O}{\text{round}}.$$

In a rapid fire automatic weapon, the time available for cooling between rounds is limited by heat transfer rate. At a firing rate of 750 rounds per minute, the cycle time per round is 80 milliseconds.

The heat transfer rate can be estimated from the following:

$q = hA\Delta T$

q = rate of heat transfer B.t.u./hr.

h = heat transfer cooefficient B.t.u./hr. of ft²

A = area ft²

ΔT = temperature difference °F.

For estimating the heat transfer rate, the following assumptions are made:

(a) ΔT

Bore surface temperature rises of 1,200°-1,400° F. in one millisecond have been measured in liquid propellant guns at the origin of rifling. Since rapid injection of cooling water immediately after firing is involved in the present method, large average temperature differences will exist during the cooling process. Here a conservative ΔT of 500° F. is assumed.

(b) Area

The chamber bore surface area is 0.375 ft². It is assumed that the injected cooling water is effectively sprayed over an area at least equivalent to this, therefore, the effective area is assumed to be 0.375 ft².

(c) Heat Transfer Coefficient

Water sprayed against hot surfaces boils violently and is rapidly vaporized. Boiling heat transfer coefficients are quite high. Coefficients of 300,000 B.t.u./hr.ft² °F. are common. Here, the heat transfer coefficient conservatively is assumed to be 250,000 B.t.u./hr.ft²°F. Based on these considerations, the rate of heat transfer is estimated to be:

$$q = \left(250{,}000 \frac{\text{B.t.u.}}{\text{hr. ft}^2\,°\text{F.}}\right)(.365 \text{ ft}^2)(500°\text{ F.}) = 4.7.10^7 \frac{\text{B.t.u.}}{\text{hr.}} \text{ or } 1.3 \times 10^4 \frac{\text{B.t.u.}}{\text{sec}}$$

Since complete cooling per round requires removal of 161 B.t.u. the required cooling time is:

$$t = \frac{161 \text{ B.t.u.}}{1.3.10^4 \frac{\text{B.t.u.}}{\text{sec}}} = 12.4 \text{ milliseconds}$$

With a total cycle time per round of 80 milliseconds there is ample cooling time available.

The above example is idealized in that perfect distribution of the cooling water over the heated surfaces is assured. While complete cooling is not usually attained in practice, a substantial portion of the heat imparted to the gun is removed. This has a major impact on firing schedule and gun system effectiveness.

FIG. **28** illustrates the disposition of the valve spools **238** and **224** in the event of a misfire, when it is desired to purge the combustion chamber **54** of all liquid propellant within the combustion chamber. In this event, the entire control cam **62** is shifted axially forward by the misfire detection switch **80**, and this shoves the control rod **226** leftward to the position illustrated in FIG. **28** where the valve spools **238** and **224** are held in the positions illustrated. The coolant water flows continuously into the combustion chamber through the coolant inlet port **244**, fills the combustion chamber **54** completely with water, and purges out all of the liquid propellant through the port **228** and the vent **222**.

A timing device, not illustrated, shuts off the flow of water through the hose **241** (see FIG. 7) after a period of time sufficient to insure complete purging of the combustion chamber.

As described above in this specification, the misfire switch **80** is controlled by the misfire detection means **78** (see FIG. 5).

The misfire detection means **78** include a gas piston **252** mounted for reciprocation within a cylinder **254**

and spring biased by a spring 256 rightward (as viewed in FIG. 5) to the position illustrated in FIG. 5 where a flange 258 engages a snapring stop 260.

A connecting rod 262 connects the gas piston 252 to the misfire switch 80 so that the misfire switch 80 is normally spring biased to the position illustrated in FIG. 5 in which the misfire switch 80 is axially aligned with the lobes 184 on the control cam 62.

A port 264 connects the bore of the barrel 52 with the interior of the cylinder 254 at the back face of the gas piston 252.

A vent port 266 is located in the sidewall of the cylinder to vent the interior of the cylinder 254 to atmosphere.

As a projectile is fired from the gun, the pressurized gases behind the projectile flow through the port 264 to momentarily move the gas piston 252 forward (leftward as viewed in FIG. 5) within the cylinder 254. This pulls the misfire switch 80 forward and out of alignment with the lobe 184 on the control cam long enough to let this lobe rotate past the misfire switch without engaging the misfire switch 80.

However, if there is a misfire, the gas piston 252 remains stationary and the misfire switch 80 engages the cam lobe 184 to divert the cam lobe into a dead side track 187 (see FIG. 43 and FIG. 6) while the other cam lobe 184 enters a relieved area. This moves the control cam 62 axially forward in the recess 188 (see FIG. 6) to disengage the gear 178 from the idler gear 176, and the rotation of the control cam 62 is stopped.

The timing of this action leaves the bolt 56 in a locked position with the breach closed.

In addition, as pointed out above, forward motion of the control cam 62 pushes the propellant fill valve 224 forward, exposing the combustion chamber fill port 228 to the port 222 at the rear of the bore 218 to permit purging of the liquid propellant from the combustion chamber 54. At the same time the water inlet valve 238 is moved forward to open the water injection port 244, and water is purged through the combustion chamber 54 to prevent cook off and to make the round inert.

The control cam disengagement disables that particular gun module but it does not disable the drive cam power train. Therefore, other modules in the banked row or cluster continue to operate and fire. Operation in this limited condition can continue until servicing. Projectiles intended for loading but passing over the disabled module are ejected at the end of the feed system transfer region.

If a projectile is missing at the feed system conveyor, a mechanical interlock system leaves a retainer in the path of the propellant fill valve 224 to prevent the valve from opening. As the module continues in a cycle of operation, a pseudo misfire occurs, and the module is disabled as described above.

Since complete propellant filling depends on fluid pressure in the propellant supply system with the monopropellant injection system described above, insufficient pressure of the propellant supply system could result in incomplete propellant filling. In the present invention when the supply pressure inadvertently drops below an established level, a pressure sensing interlock system (see FIG. 44) stops operation of the complete group (row or cluster of modules).

The projectile feed system is best shown in FIG. 31.

The projectile feed mechanism 68 employs a short endless conveyor 149 which is driven by a sprocket drive 270 from the drive motor 164.

As best illustrated in FIG. 32, the conveyor 140 mates with a transfer mechanism 272 to accept projectiles 84 from a conventional belt or linkless feed. The transfer mechanism 272 includes a shifting device which selects from separate projectile supplies to switch types of ammunition. The spring clip cradles 146 are the primary elements of the conveyor 149. The tangs on the ends of the spring clip cradles slide in guide grooves in the conveyor frame. The cradles are coupled to form an endless, flexible chain.

Two configurations of the conveyor 149 are illustrated in FIGS. 31–32 and in FIG. 33. In FIGS. 31 and 32 a flat conveyor passing over a banked row of modules is illustrated and in FIG. 33 a circular conveyor wrapping around a cluster of three modules is illustrated.

The flat conveyor configuration shown in FIGS. 31 and 32 demonstrates the loading scheme of the present invention which depends on a unique sequencing arrangement. In FIG. 32 a banked row of five modules served by the conveyor 149 are indicated by the reference numerals 1–5. The projectiles 84 move along the conveyor from right to left and are numbered in groups of five, e.g. (5, 4, 3, 2, 1) (10, 9, 8, 7, 6), etc. The modules are also numbered (5, 4, 3, 2, 1) and are loaded in the sequence 1 through 5 and fire, of course, in the same sequence. Center-to-center spacing of the projectiles in the conveyor (1.75 in. for 30 mm) is ½ the center—center spacing of the modules (3.5 in. for 30 mm).

Assume projectile 1 is at the loading position for module 1. The loading lever on the module kicks the projectile out of the conveyor and into the module. The conveyor travels 1.75 inches between loadings. Projectile 2 as 1.75 inches away from the loading position for module 2 at the start but has now arrived in position and is loaded. Projectile 3 is now 1.75 inches away from the module 3 and will arrive at the loading position on time. The loading progresses until projectile 5 is loaded in module 5, this projectile having moved 7.0 inches while the other projectiles were loading. By the time projectile 5 has been loaded, projectiles 10, 9, 8, 7 and 6 have moved into positions occupied by projectiles 5, 4, 3, 2 and 1 at the start. The process continues in perfect time, with projectile 6 loading into module 1, projectile 7 loading into module 2, etc. This loading scheme applies to any number of modules.

The circular conveyor for a cluster of three modules, shown in FIG. 33, uses the same loading scheme as described above. Since the conveyor is circular, the cradles can take the form of pockets in a wheel-like structure. A minimum of six cradles or pockets are needed to properly feed the cluster. Nine pockets are shown in FIG. 33 to reduce the rotational speed of the conveyor and the centrifugal force imposed on the projectiles, thus reducing the force that must be exerted by the projectile loading levers at the modules.

Other cluster configurations as illustrated in FIGS. 34–39 are readily arranged and serviced by the projectile loading mechanism 68 as described above.

The modular system of the present invention can accomodate recoil adapters similar to those on the M-61 gun to reduce recoil forces. A banked row or cluster or modules can be supported mutually at the breach end of the barrels by a bracket structure that receives a pair (or more) of recoil adapters. An additional bracket structure mutually supports the rear of the modules and engages a short fixed slide to accomodate recoil travel. The latter bracket includes a provision for boresighting.

The impact of caseless operation on gun design is best illustrated in FIG. 41 which compares a 30 mm liquid propellant modular gun projectile with a conventional 20 mm round for the M-61 gun. Due to the similarity in length and diameter between the liquid propellant projectile and the solid propellant round, it is feasible to directly substitute the 30 mm projectile for the existing 20 mm cartridge. Some modifications are, of course, required due to slight differences in configuration but the overall volume is substantially the same.

FIG. 40 compares the diameters of a liquid propellant modular gun projectile in a 30 mm size with the cartridge and projectile size for a conventional 30 mm solid propellant round. This figure graphically illustrates the space and weight savings which can be achieved for the projectile feed systems in the 30 mm gun size with the liquid propellant modular gun of the present invention.

While we have illustrated and described the preferred embodiments of our invention, it is to be understood that these are capable of variation and modification, and we therefore do not wish to be limited to the precise details set forth, but desire to avail ourselves of such changes and alterations as fall within the purview of the following claims.

We claim:

1. A drive cam for reciprocating a bolt back and forth between a rearward, projectile loading position and a forward, projectile firing position in a gun, said drive cam comprising,

a hollow cylindrical member having a longitudinal axis disposed parallel to the axis of reciprocation of the bolt and mounted for rotation about said longitudinal axis,

a first spiral cam track formed on the inside of the hollow cylindrical member and engageable with a cam follower on the bolt to drive the bolt forward, and

a second spiral cam track separate from the first spiral cam track and formed on the interior of the hollow cylindrical member and engageable with the cam follower of the bolt to drive the bolt rearward and wherein the hollow cylindrical member includes dwell area means at the front and rear for permitting rotation of the hollow cylindrical member without producing axial movement of the bolt.

2. The invention defined in claim 1 including gear teeth on the outer periphery of the hollow cylindrical member at one end of the hollow cylindrical member for engagement with a driving gear.

3. A drive cam for reciprocating a bolt back and forth between a rearward, projectile loading position and a forward, projectile firing position in a gun, said drive cam comprising,

a hollow cylindrical member having a longitudinal axis disposed parallel to the axis of reciprocation of the bolt and mounted for rotation about said longitudinal axis,

a first spiral cam track formed on the inside of the hollow cylindrical member and engageable with a cam follower on the bolt to drive the bolt forward,

a second spiral cam track formed on the interior of the hollow cylindrical member and engageable with the cam follower of the bolt to drive the bolt rearward, and including a bolt mounted for reciprocation within the interior of the hollow cylindrical member, said bolt having a radially projecting cam follower at one end of the bolt and mounted for sliding movement radially inward and radially outward of the bolt, and biasing means for biasing the cam follower radially outward of the bolt.

4. The invention defined in claim 3 wherein the hollow cylindrical member includes dwell area means at the front and rear for permitting rotation of the hollow cylindrical member without producing axial movement of the bolt and wherein the forward dwell area means includes a radially extending slot having sidewalls engageable with the cam follower for rotating the bolt to a locked position.

5. The invention defined in claim 4 including receiver cam means associated with the forward dwell area means and cam follower for moving the cam follower radially inward of the bolt and out of engagement with the sidewalls of the slot after the bolt has been rotated to the locked position.

* * * * *

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Date: May 30, 1961

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Date: June 30, 1964

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Title: Ignition Device for Liquid Primers
Date: January 30, 1968

May 30, 1961 C. M. HUDSON 2,986,072

LIQUID FUEL CATAPULT

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Fig. 1.

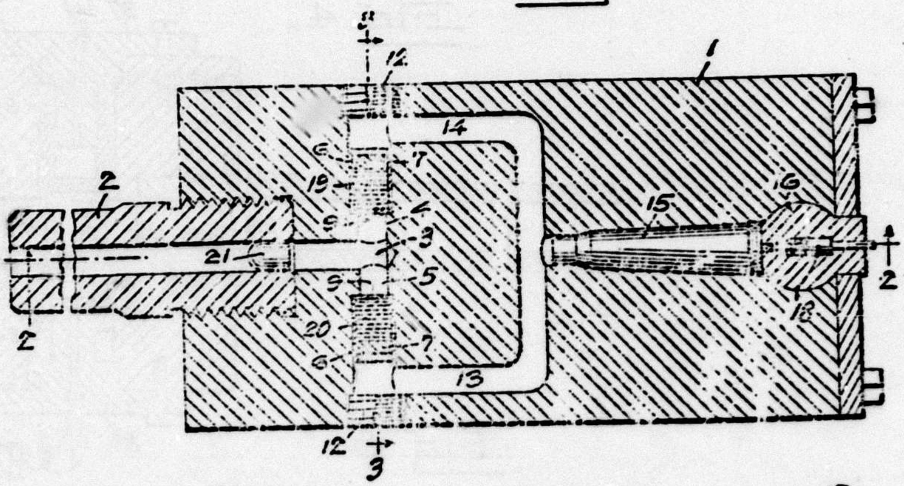
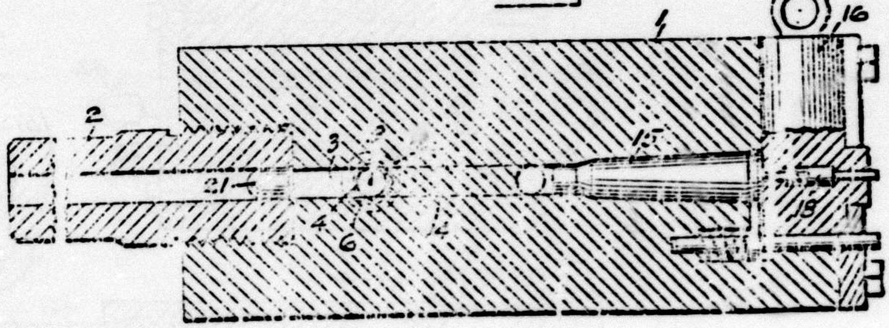


Fig. 2.



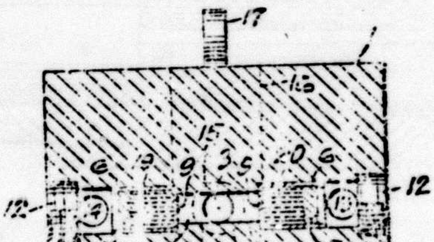


Fig. 3.

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ATTORNEYS

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LIQUID FUEL CATAPULT

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Fig. 4.

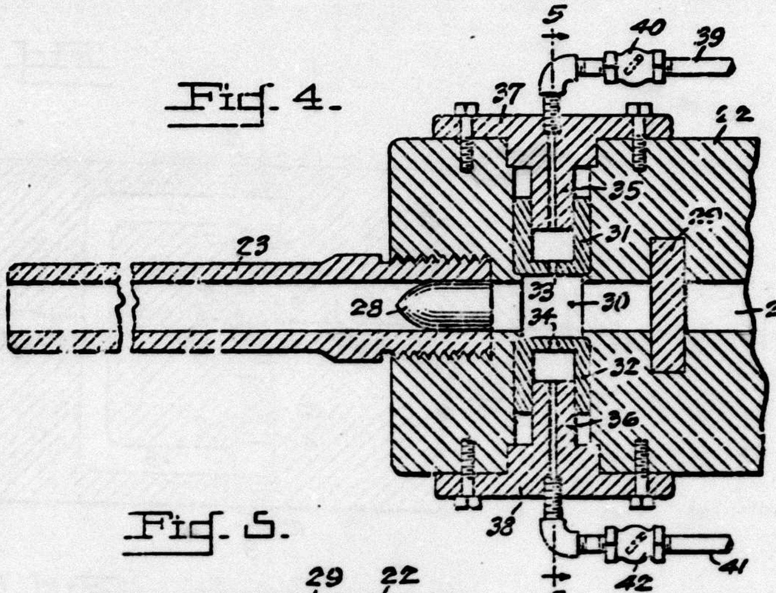


Fig. 5.

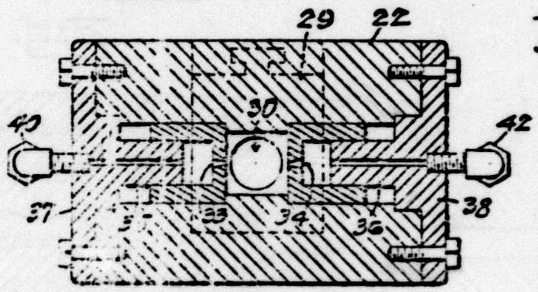
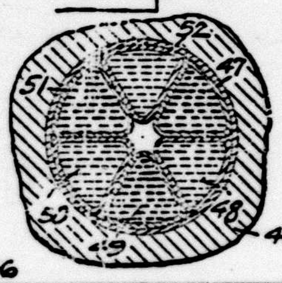


Fig. 7.



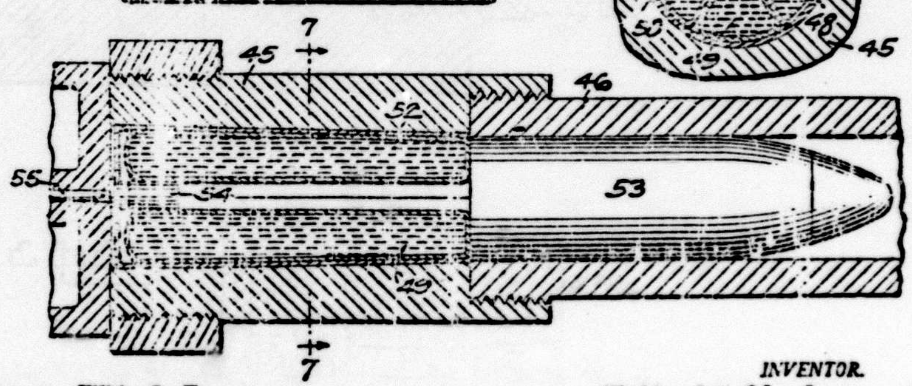


Fig. 6.

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ATTORNEYS

United States Patent Office

2,986,072

Patented May 30, 1961

2,986,072

LIQUID FUEL CATAPULT

Colin M. Hudson, Arlington, Va., assignor to the United States of America as represented by the Secretary of the Army

Filed Nov. 19, 1952, Ser. No. 321,534

1 Claim. (Cl. 89—7)

(Granted under Title 35, U.S. Code (1952), sec. 266)

The invention described in the specification and claim may be manufactured and used by or for the Government for governmental purposes without the payment to me of any royalty thereon.

This invention relates to guns and in particular to a novel system for propelling projectiles from gun barrels or tubes.

In a gun, when the charge is fired, the gas pressure immediately begins to rise in the powder chamber. The projectile at first remains stationary because of the friction fit with the bore but beyond a certain pressure the friction bond is broken an the projectile begins to move forward in the bore. This movement tends to relieve the pressure by increasing the volume within which the gases may expand. But the burning of the charge is not instantaneous and the powder continues to burn and evolve gases as the projectile moves. As long as the projectile is in the bore it is acted upon by a fairly high pressure which reaches a maximum at some point between its original position and the muzzle and functions as an accelerating force. The point in the bore at which the projectile is driven by maximum pressure is determined by a number of factors and in many of the prior art guns this point is about a foot in advance of the powder chamber. As will later more fully be explained my invention will yield a substantial advance in the art of propellants by providing a controlled rate of pressure generation leading to higher projectile velocities at lower peak pressure.

It is a broad object of my invention to improve on the weapons now in use.

It is a further and more particular object of my invention to provide a system for propelling projectiles in which highly reactive liquid chemicals are used in place of the conventional solid propellants.

It is a still further object of my invention to provide a reactive chemical weapon which is completely safe to operate, and is reliable in use.

Other objects of the invention will be evident from the following description and the appended drawings in which:

Figure 1 is a fragmentary longitudinal section view of my novel weapon.

Figure 2 is a section view taken along lines 2—2 of Figure 1 and looking in the direction of the arrows.

Figure 3 is a section view taken along lines 3—3 of Figure 1 and looking in the direction of the arrows.

Figure 4 is a fragmentary longitudinal section view of another species of my novel weapon.

Figure 5 is a section view taken on lines 5—5 of Figure 4 and looking in the direction of the arrows.

Figure 6 is a fragmentary longitudinal section view of still another species of my invention.

Figure 7 is a section view taken on lines 7—7 of Figure 6 and looking in the direction of the arrows.

Described briefly my invention consists of a system whereby self igniting chemicals may be intimately intermixed so that their spontaneous reaction produces the pressures for projectile ejection and flight.

In the specification and in the claim appended thereto the word "hypergolic" is intended to be used as defined in the Defense Department's Glossary of Guided Missile Terms, "Capable of igniting spontaneously upon contact."

Referring now more particularly to Figure 1, wherein a cartridge is used for the pressure source reference character 1 indicates generally a breech block having at the forward end thereof a barrel or tube 2 threadedly received in a cavity and aligned with a combustion chamber 3. Passages 4 and 5 lead from chamber 3 on opposed sides thereof and hold cylinders 6 therein. The cylinders are each provided with an orifice 9 in the end wall proximate the combustion chamber which orifice is normally covered with a frangible plug, and have a piston 7 for a purpose that will presently appear. The bores 4 and 5 are closed at their distal ends by plugs 12 which may be removed to insert the cylinders in a loading operation. Leading rearwardly from the outer portion of bores 4 and 5 are two arms 13, 14 of a forked cavity terminating in a cartridge chamber having nested therein a cartridge 15. A plug 16 slidable in breech block 1 has a lifting eye 17 thereon and carries a spring biased firing pin 18 so arranged that when the plug is properly seated in the breech block the firing pin is aligned with the primer in the cartridge.

The several injector cylinders 6 are adapted to receive the hypergolic fluids. In general a reactive fuel 19 is contained in one cylinder and an oxidizer 20 is contained in the other. Specific examples of such combinations that have been successfully used are hydrazine (N_2H_4) with hydrogen peroxide (H_2O_2), and hydrazine with nitric acid. It will be understood however that the above examples are illustrative only and my invention contemplates the use of any and all substances and compounds that react spontaneously and violently upon contact.

It can be readily seen that upon firing of the cartridge 15 by moving firing pin 18 forward, the gases of combustion create a high pressure in passages 13 and 14 and transmit same to the outer faces of pistons 7. The pistons will urge inwardly upon the confined hypergolic fuel 19 and oxidizer 20 fracturing the frangible covering over the orifices 9 and the several liquids will empty therethrough and intermingle within combustion chamber 3 with a resultant spontaneous chemical reaction and the production of a high pressure to force projectile 21 out of the barrel.

Attention is now directed to Figures 4 and 5 wherein a variant of my novel weapon is revealed. Reference character 22 indicates a breech block having at the forward end thereof a barrel 23 threadedly received in a cavity and aligned with passageway 24 which is selectively closed by sliding plate 29. A traverse passage intersects passage 24 to form a combustion chamber 30. On opposed sides of the chamber are slidable injector pistons 31 and 32 having ports 33 and 34 in the closed ends thereof and constructed to slidably receive bosses 35 and 36 formed on the ends of plugs 37 and 38 respectively. Pipe line 39 having a one way check valve 40 serves to connect with a pressurized source containing one of the hypergolic fluids and to a bore in plug 37; and pipe line 41 having a one way check valve 42 serves to connect a pressurized source of the other reactant to a bore in plug 38.

The weapon is illustrated in condition for firing and a cycle thereof will now be described. A valve (not shown) is triggered which simultaneously admits metered amounts of the hypergolic fluids at a high pressure into pipes 39 and 41 respectively. The reactants will quickly fill the volumes between boss 35 and cylinder 31 and between boss 36 and cylinder 32 and a portion of each will be ejected through ports 33 and 34 into combustion chamber

30 where they will meet and intermingle to create a pressure. This pressure acting upon the exposed face of cylinders 31 and 32 will force them toward bosses 35 and 35 respectively thus emptying the filled volumes into the combustion chamber with great force and the resulting explosion will send projectile 28 upon its trajectory. It should be noted that the area of the cylinder face exposed to combustion chamber pressure is greater than the area of the cylinder face exposed to the fluid pressure. Thus a regenerative piston effect is obtained and the pressure of the fluid can be greater than the initial pressure in the chamber but the resultant force will still move the piston back forcing the reactants therein into the chamber.

After the projectile has left the muzzle of the barrel the chamber pressure drops and the cylinders are returned to their forward position by expansion of the trapped air compressed behind the open ends of the cylinders during rearward motion thereof and a projectile feeding mechanism (not shown) lifts sealing block 29 up and forces a new projectile into the barrel ready for the next shot.

It can be readily seen that the amount of propellant is readily controlled by limiting the amounts fed to the pistons or limiting the motion thereof whereby the point of maximum pressure acting on the projectile may be adjusted. Also the rate of propellant injection may be controlled by proper selection of piston face areas.

Another species of my invention is disclosed in Figures 6 and 7. Reference character 45 indicates generally a breech block secured to barrel 46 which is shaped to form a chamber to receive a novel arrangement of the hypergolic fluids. A metallic casing holding a primer 54 at the rear thereof holds the hypergolic liquids in combustible elongated containers arranged longitudinally within the casing with each liquid sandwiched between two dissimilar ones substantially as shown in Figure 7 wherein, for example, reference characters 47, 49 and 51 indicate a reactive fuel and 48, 50 and 52 indicate an oxidizer. A projectile 53 is frictionally held in the barrel and a firing pin 55 is aligned with the primer 54 in the usual manner.

When the firing pin explodes the primer the flame moves down the longitudinal axis of the chamber and destroys the containers. The hypergolic liquids thereupon mix and the resulting reaction ejects the projectile from the barrel.

Among the advantages of the above described invention are: (1) higher propellant impetus by reason of the lowered propellant gas molecular weights

$$\left(FOC\frac{1}{W}\right)$$

which are obtainable with such reactant combinations as H_2O_2—N_2H_4, together with the greater energy content of such mixtures, (2) controlled rate of pressure generation by control over propellant injection rates, leading to higher velocities at lower peak pressures, and (3) comparable velocities at lower ratios of propellant to projectile weight by reason of the above, so that less propellant and chamber volume is required resulting in a shorter gun.

An extensive series of firings has been conducted on a gun built in accordance with the principles set out in this invention. A projectile velocity of 6200 ft./sec. at a propellant to projectile mass ratio of 3.6 was obtained. For a propellant to projectile mass ratio of 1.5 the maximum velocities exceeded nitrocellulose values by as much as 20% at comparable or lower chamber pressures. Velocities as high as 8700 ft./sec. have been attained at substantially lower peak pressures than published figures for nitrocellulose powder.

In a general manner I have in the above description disclosed what I deem to be practical and efficient embodiments of the present invention. It should be well understood that I do not wish to be limited thereto as there might be changes made in the arrangement, disposition and form of the parts without departing from the principles of the present invention as comprehended within the scope of the accompanying claim.

I claim:

A firearm comprising a breech casing, a barrel affixed to said breech casing, a combustion chamber formed in said casing and communicating with said barrel, at least two opposed bores in said casing one end of which communicates with said combustion chamber, a counterbore at the other end of said bores, hollow injection cylinders fixedly received within said counterbores, said cylinders containing a predetermined volume of hypergolic reactants and having at one end thereof a normally sealed orifice opening into said bores, a piston at the other end of said cylinders, a pressure generating cartridge received within said casing, a series of passages in said casing communicating between said pistons and said cartridge, whereby said pistons are actuated to break said seal and inject said reactants into said combustion chamber in response to firing said cartridge.

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June 30, 1964 R. A. JUKES ETAL 3,138,990

LIQUID PROPELLANT MACHINE GUN

Filed Oct. 9, 1961

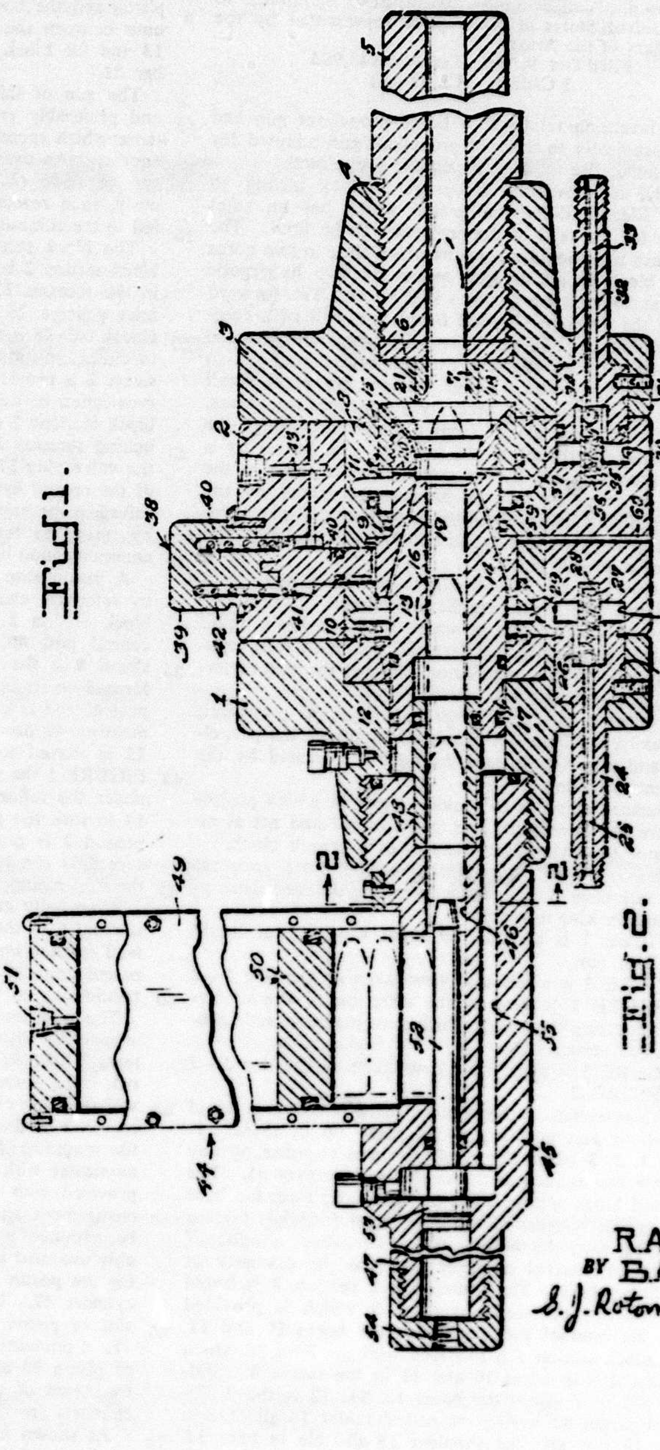
Fig. 1.

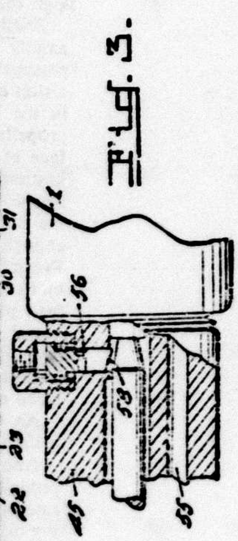
Fig. 3.

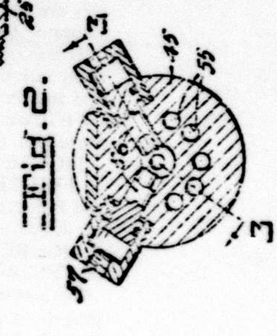
Fig. 2.

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3,138,990

LIQUID PROPELLANT MACHINE GUN

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Filed Oct. 9, 1961, Ser. No. 143,983
3 Claims. (Cl. 89—7)

This invention relates to a liquid propellant gun and more specifically to a liquid propellant gun adapted for high rates of fire utilizing hypergolic propellants.

Briefly, our invention comprises a block having an axially slidable differential piston which has an axial passage for the feed of the projectiles to be fired. The piston has two shoulder portions which slide in two bores in the block to act as feed means for two hypergolic propellants which are fed into said bores. The forward face of the differential piston forms one wall of a combustion chamber and the hypergolic propellants are fed to the combustion chamber through orifice passages in the differential piston. These passages are made small enough to obviate any necessity for propellant valves. Projectiles are fed axially from a magazine through the block and differential piston into the gun barrel by a feed piston actuated by the gun. The projectile in the barrel is propelled by the pressure generated by the burning of the hypergolic propellants and the other projectiles in the feed line act as an obturator and take the place of a breech block.

An object of this invention is to provide a liquid propellant gun utilizing hypergolic propellants.

Another object of the invention is to provide a liquid propellant gun having a differential piston to feed separate propellants to a combustion chamber through metering orifices in the piston.

Yet another object is to provide a liquid propellant gun having a differential piston for supplying the propellants and a projectile feed mechanism operated by the differential piston.

A further object is to provide a gun in which projectiles are fed in an axial line to the barrel and act as an obturator to obviate the necessity of a breech block.

These and other objects will become more apparent when reference is had to the following detailed description and drawing in which:

FIGURE 1 is an axial sectional view of our liquid propellant gun.

FIGURE 2 is a sectional view taken on the line 2—2 of FIGURE 1 looking in the direction of the arrows and illustrating the means which prevents retrograde projectile movement, and

FIGURE 3 is a sectional view taken on the line 3—3 of FIGURE 2.

With reference to the drawing there is shown a liquid propellant gun having a block made up of three sections 1, 2, 3 which are rigidly secured together by any suitable means such as through bolts (not shown). The forward block section 3 has the internally threaded bore 4 in which is received the gun barrel 5 and is further provided with the bore 6 which receives the collar 7 having an internal diameter equal to the diameter of the barrel bore. The central block section 2 is bored and receives the sleeve member 8 which is provided with the internal shoulder 9 and the bores 10 and 11. The block section 1 is provided with the bore 12 which is coaxial with bores 10 and 11 in the sleeve 8. Slidably received within the bores 10, 11, 12 is the differential piston 13 having integral shoulder 14 slidable in bore 10 and attached shoulder 15 slidable in bore 11. The differential piston 13 has the central longitudinal passage 16 for the passage therethrough of projectiles

and reduced end portion 17. The forward portion of the differential piston is flared as indicated at 18 and is provided with orifice channels 19 and 20 which provide communication between the forward face of the piston and the bores 10 and 11, respectively. The volume between the front face of the differential piston 13 and the block section 3 forms a combustion chamber 21.

The gun of this invention utilizes liquid propellants and preferably propellants of the hypergolic type, i.e. those which spontaneously ignite upon contact with one another. An example of hypergolic reactants is hydrogen peroxide (H_2O_2) and hydrozine (N_2H_4). Obviously, such reactants cannot be premixed and must be fed to the combustion chamber 21 separately.

The block section 1 is provided with recess 22 and block section 2 has a mating recess 23. Mounted within the recesses 22 and 23 is the valve plug 24 having inlet passage 25 for one of the hypergolic reactants. Check ball 26 is received in the valve plug 24 and urged to closed position by spring 27 seated in cup 28. The sleeve 8 is provided with passage 29 which affords communication between inlet passage 25 and bore 10. The block sections 2 and 3 are provided with corresponding mating recesses 30 and 31, respectively, which receive the valve plug 32 having inlet passage 33 for admission of the second hypergolic reactant. Check ball 34 is received in the valve plug 32 and urged to closed position by spring 35 received in cup 36. Passage 37 affords communication between the inlet passage 33 and bore 11.

A piston stop mechanism is indicated in its entirety by reference character 38. Threadedly received in the block section 2 is the cup shaped member 39 having central post 40. Slidably mounted in the block and sleeve 8 is the stop member 40 having the piston 41 formed on its upper end. The spring 42 surrounds the post 40 and reacts against the piston 41 to urge the stop member 40 downwardly. When the differential piston 13 is moved to the left from the position shown in FIGURE 1 the stop member 40 may move downwardly under the influence of spring 42 in front of shoulder 14 to lock the piston in rearward position. The block section 2 is provided with passage 43 by which pressure fluid can be admitted below the piston 41 to raise the stop member 40 against the action of spring 42.

Threadedly connected to the rearward end of block section 1 is the projectile feed mechanism 44. This feed mechanism forms the subject matter of a separate patent application but it will be described here in its relationship to the remainder of the gun.

The feed mechanism comprises a housing 45 having a centrally disposed projectile feed channel 46 and integrally formed cylinder 47 coaxial with the feed channel. The forward end of the housing 45 is provided with a pilot extension 48 which slidably receives the rear end of differential piston 13. A fluid tight projectile magazine 49 is mounted on the housing and communicates with the feed channel 46. The magazine is provided with a follower 50 slidable therein in sealed engagement and port 51 by which pressure fluid may be admitted to force the follower downwardly. Slidably mounted in the housing is the feed plunger 52 having the piston 53 connected thereto and slidable in the cylinder 47. Gas pressure may be applied to the rear side of piston 53 through the port 54 in the cylinder 47. Communication is provided between the front face of piston 53 and the rear face of differential piston 13 by means of channels 55 in the housing 45 and these channels are filled with an incompressible fluid.

As shown in FIGURES 2 and 3 the projectile feed mechanism is provided with means to prevent retrograde motion of the projectiles after they are fed. The hous-

ing 45 is provided with a plurality of radially slidable stop plungers 56. These plungers are urged into the feed channel by gas pressure applied to the upper sides thereof through ports 57 and the lower ends thereof are rearwardly bevelled as shown at 58. When a projectile is fed forwardly the plungers are cammed outwardly to permit passage of the projectile and then snap inwardly by gas pressure to prevent reverse projectile movement.

Operation

In idle condition the differential piston 13 will be moved to left from the position shown in FIGURE 1 and locked by stop member 40. To place the gun in operation, gas pressure is supplied to channel 43 to raise the stop member 40 and also to the ports 51, 54 and 57 of the projectile feed mechanism. Gas pressure applied to the feed plunger piston 53 will move the plunger 52 to the right and feed a projectile into the gun barrel 5. When the piston 53 moves to the right the liquid in channels 55 will act as a hydraulic link and move the differential piston 13 to the position shown in FIGURE 1 by acting on the rear face thereof.

The hypergolic reactants are supplied under pressure to the inlet passages 25 and 33 and flow past the check valves into bores 10 and 11, respectively. The volume of these bores is proportioned to provide a measured amount of the propellants. The sleeve 8 is provided with an annular air channel 59 and the block section 2 has the scavenging port 60 therein to prevent the passage of propellants from one bore to the other.

The propellants now begin to feed from the bores 10 and 11 to the combustion chamber 21 by way of the orifice channels 19 and 20, respectively. The diameter of these channels is selected to restrict the feed rate to give the desired burning rate. In this manner the necessity of valves in these channels is obviated. As soon as the hypergolic reactants meet in combustion chamber 21 combustion is initiated and the pressure therein begins to rise. When this pressure has risen sufficiently to overcome the gas pressure acting on piston 53 of the feed plunger and the inlet pressure of the propellant, the differential piston begins to move backwardly. This increases the pressure in the bores 10 and 11 and closes the inlet check valves. The increased pressure on the propellants in the bores 10 and 11 accelerates the feed thereof through the orifice channels 19 and 20 and increases the rate of combustion until the piston has moved to the rearward end of its travel. Incident to the rearward movement of the differential piston 13, the hydraulic link causes retraction of the feed plunger to permit another projectile to feed from the magazine 49 into the feed channel 46.

When gas pressure is built up in combustion chamber 21 the projectile which is in the barrel is propelled forwardly at high speed. The projectiles occupying the space between the combustion chamber and feed mechanism are prevented from rearward movement by the plungers 56. It will be noted that the diameter of the projectiles and the diameter of the passage 16 are substantially the same so that the projectiles in the passage act as an obturator and preclude the necessity of any breech block mechanism.

When the projectile clears the barrel of the gun the pressure in the combustion chamber immediately drops off. The gas pressure acting on the feed piston 53 now moves the feed plunger forward and through the hydraulic link also moves the differential piston 13 forwardly so that the firing may automatically repeat.

It will be apparent that the embodiment shown is only exemplary and that various modifications in construction and arrangement may be made without departing from the scope of the invention as defined in the subjoined claims.

We claim:

1. In a liquid propellant gun, the combination comprising, a composite block including an intermediate section, a forward section and a rearward section, said sections having axial aligned bores therethrough, a sleeve in said central section and having an internal annular shoulder therein, there being forward and rearward axial bores therein and disposed, one each, on each side of said shoulder, said last named bores being coaxial with respect to said bores in said forward and rearward sections; a single differential piston mounted for axial reciprocation in said bores in said sleeve and said bore in said rearward section, there being an integral shoulder thereon, said shoulder slidable in the rearward bore of said sleeve, a detachable shoulder secured on the forward end of said piston and slidable in the forward bore in said sleeve, there being a central axial passage through said piston and being in alignment with the bores in said forward and rearward sections, said detachable shoulder being flared to form a combustion chamber between the forward face of said piston and said forward section, said piston having metering orifice channels communicating between said combustion chamber and said bores in said sleeve; valve means in said block for admitting hypergolic reactants to said combustion chamber through said channels, the increase in pressure from combustion of the hypergolic reactants in said combustion chamber being effective to move said piston rearwardly to accelerate the feed of said reactants into said combustion chamber; a barrel connected to said forward section, said barrel having an axial bore of the same diameter as said passage in said piston and in alignment therewith; means connected to the rearward section for feeding projectiles into said passage in said piston and barrel; a differential piston stop mechanism in said block for locking said piston in a rearward cocked position; scavenging means for said gun disposed in said block sections for preventing passage of propellants from one of said bores in said sleeve to the other; and means for preventing retrograde motion of the projectiles after being fed into said piston and disposed between said feeding means and said rearward section comprising a series of inwardly urged, radially disposed plungers having beveled inner ends whereby when a projectile is fed forwardly, said plungers are cammed outwardly and snap inwardly upon forward clearance of a projectile.

2. In a liquid propellant gun as defined in claim 1, wherein said differential piston stop mechanism comprises a plunger radially slidable in said intermediate block, said plunger being projected in front of said shoulder on said differential piston when said piston is in a rearward position and spring means to urge said plunger inwardly, said plunger being movable outwardly to free said shoulder by the application of fluid pressure to the under side thereof.

3. In a liquid propellant gun as defined in claim 1, wherein said scavenging means comprises an annular scavenging channel intermediate said bores in said sleeves and a radial scavenging port providing communication between said channel and the exterior of said block.

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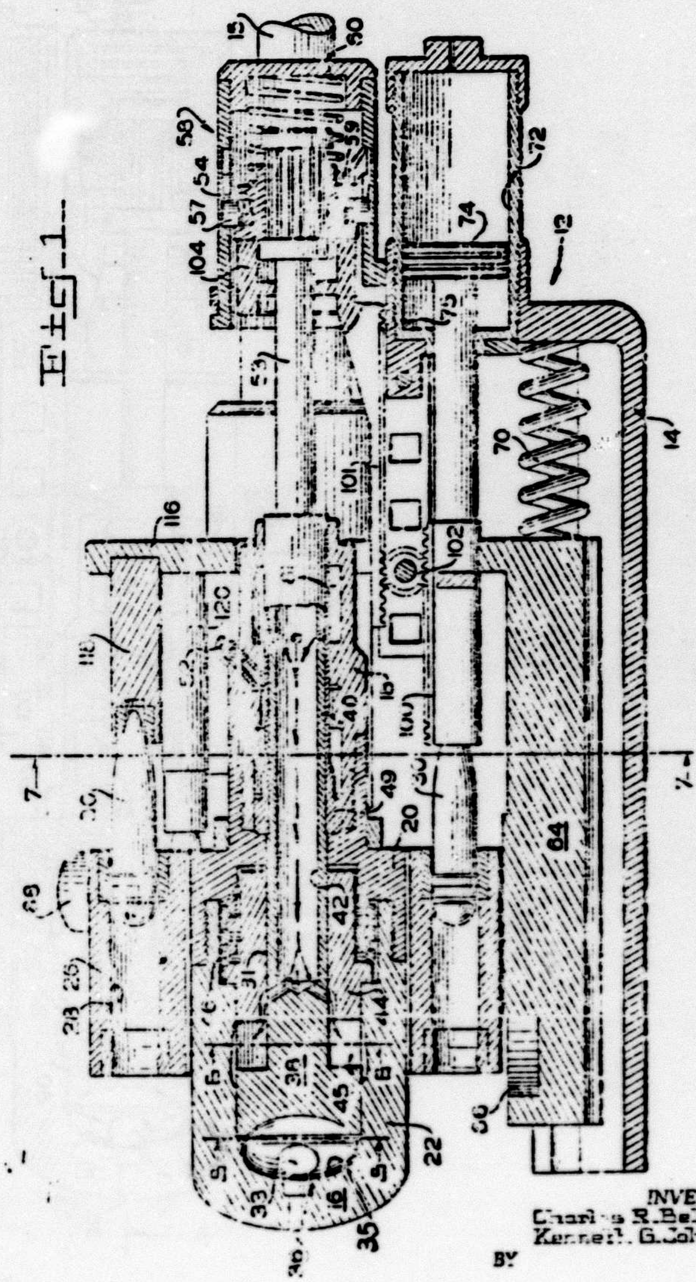

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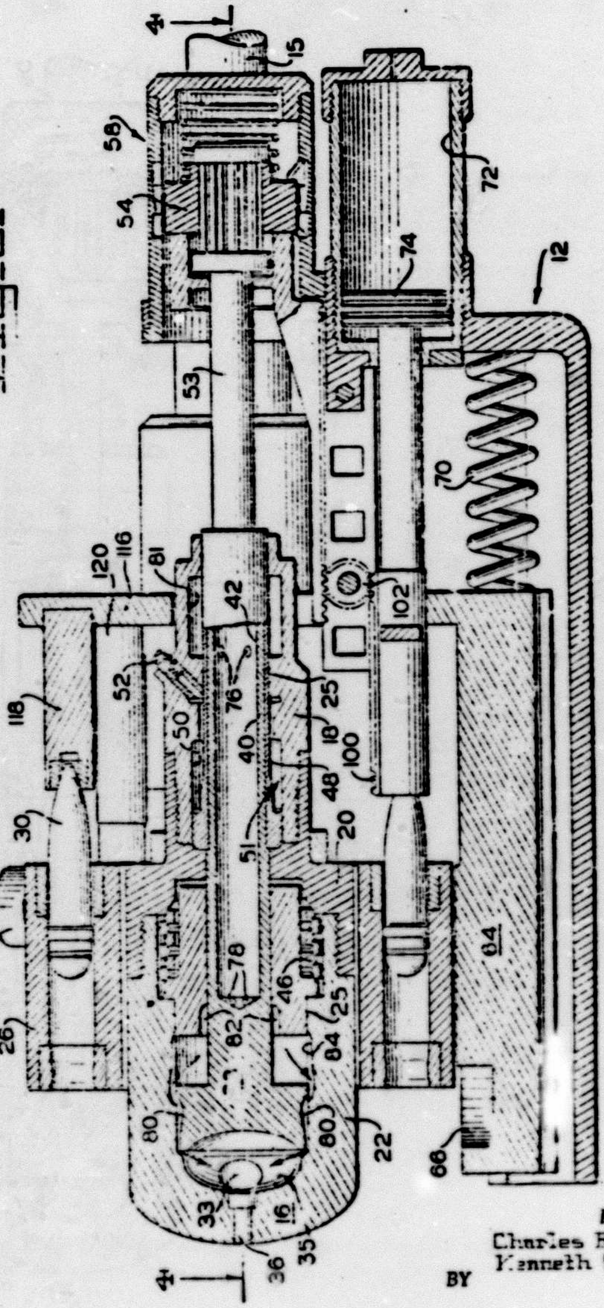
Dec. 8, 1964 C. R. BELL ETAL 3,160,064

LIQUID PROPELLANT GUN

Filed May 27, 1957 5 Sheets-Sheet 2

Fig-2



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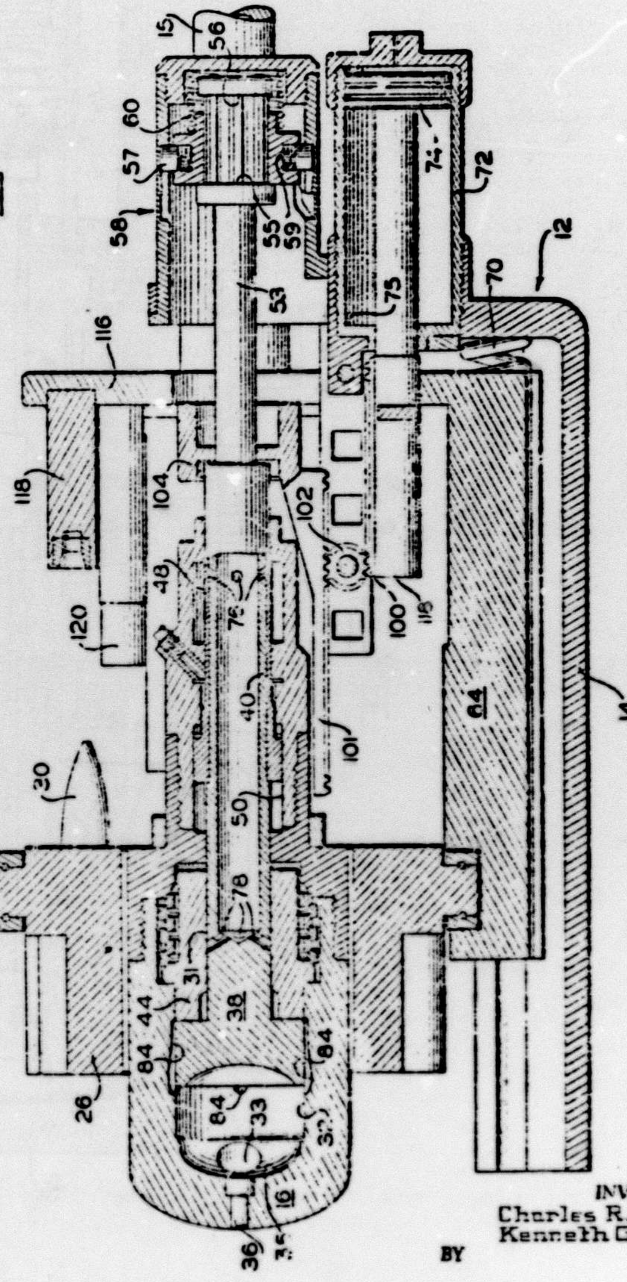
LIQUID PROPELLANT GUN

Filed May 27, 1957 5 Sheets-Sheet 3

FIG. 3



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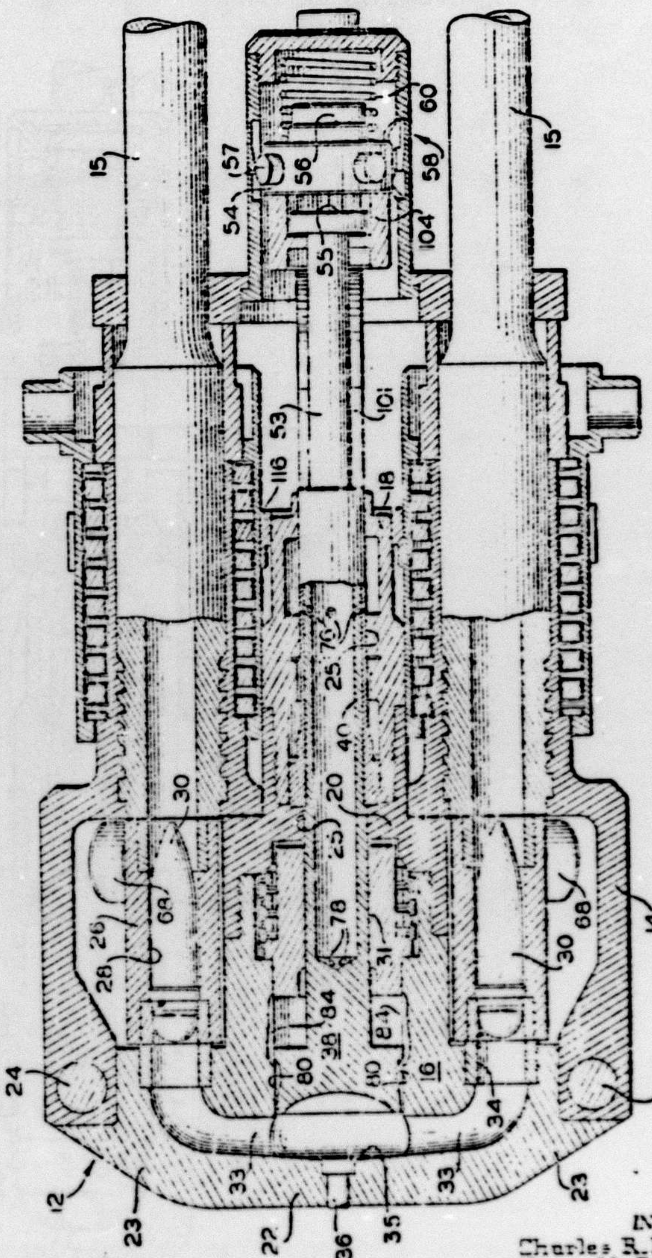

Fig-4

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LIQUID PROPELLANT GUN

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Fig. 5

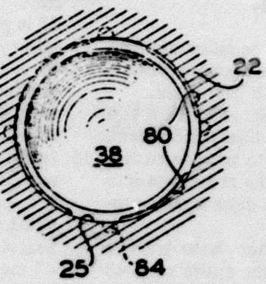


Fig. 6

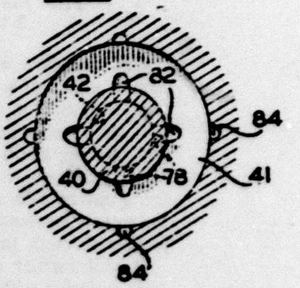


Fig. 7

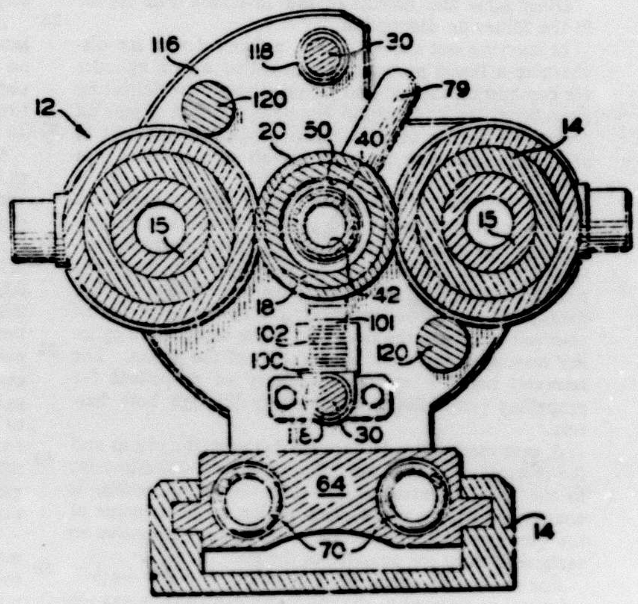
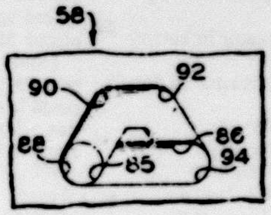


Fig. 8



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1

3,160,064

LIQUID PROPELLANT GUN

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Filed May 27, 1957, Ser. No. 661,983
2 Claims. (Cl. 89—155)

Our invention relates to a revolver-type automatic gun having a pair of barrels and more particularly to such a gun disposed for operation by a liquid propellant.

It is an object of our invention to provide such a gun with a firing device for discharging the liquid propellant.

A further object of our invention is to provide such a firing device with a reservoir to meter the propellant into the quantities required for simultaneous discharge of projectiles through the barrels.

A still further object of our invention is to provide such a device with means for passing the entire metered quantities of the propellant to the combustion cylinder.

An additional object of our invention is to provide such a device which is operable by an actuator of the gun.

Other aims and objects of our invention will appear in the following description.

In carrying out our invention, a firing device for discharging a liquid propellant is provided with a cylinder for combustion thereof and passage means for delivering gases from the combustion simultaneously to a pair of firing stations for action against projectiles disposed in axial alignment with the twin barrels of a revolver-type gun.

The firing device is provided with a reservoir adjacent the combustion chamber and a piston biased to a battery position and disposed for reciprocal axial operation responsive to the combustion. Valves disposed between the piston, the stem of the piston and the housing control passage of the propellant from a supply thereof to the reservoir and from the reservoir to the combustion cylinder responsive to the axial operation of the piston. The reservoir holds a sufficient quantity of propellant for propelling projectiles simultaneously through both barrels.

A cam mechanism is disposed between the piston and the receiver to control operation of the valves responsive to the axial reciprocation, and a sleeve mechanism is connected through racks and a pinion to the actuator of the gun for operation of the cam device responsive to reciprocation of the actuator of the gun.

For a more complete understanding of our invention, reference is directed to the following explanation and the accompanying drawings in which:

FIG. 1 is a longitudinal section of the gun with the actuator in seared position;

FIG. 2 is similar to FIG. 1 with the actuator in battery position;

FIG. 3 is similar to FIG. 1 with the actuator in forward position;

FIG. 4 is a view along line 4—4 of FIG. 2;

FIG. 5 is a view along line 5—5 of FIG. 1;

FIG. 6 is a view along line 6—6 of FIG. 1;

FIG. 7 is a view along line 7—7 of FIG. 1; and

FIG. 8 is a developed view of the follower cam.

Accordingly, a gun 12 includes a receiver 14 with twin barrels 15 secured therein and a housing 16 including forward, intermediate and rearward sections 18, 20 and 22, respectively, removably secured together and provided with a cylindrical aperture 25 of varying diameters therethrough. Rearward section 22 is substantially T-shaped in configuration and includes lateral arms 23 secured to receiver 14 by pins 24.

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A drum 26 including chambers 28 for projectiles 30 is disposed for rotation around the leg portion of rearward section 22 and intermediate section 20 to simultaneously convey diametrically-disposed chambers 28 to firing stations in respective alignment with barrels 15.

Aperture 25 includes a cylinder 32 in rearward section 22 connected by tubes 33 in arms 23 to openings 34 in respective alignment with barrels 15. Rearward section 22 is provided with an electric igniter 36 so as to extend into cylinder 32. A piston 38 axially slidable in cylinder 32 is biased to a rearward position by a spring 60 and provided with a stem 40 having a cylindrical compartment 42 therein. The portion of cylinder 32 between the rear end of piston 38 and the rear end of aperture 25 forms a combustion chamber 35. A cylindrical seat 44 is rotationally fixed within the portion of aperture 25 which is disposed in intermediate section 20 and the seat is provided with an axial bore 31 to slidingly receive stem 40. Seat 44 and piston 38 are spaced to provide a reservoir 45 therebetween for inclosing the quantity of propellant required for simultaneous discharge of barrels 15 when piston 38 is in the rearward position. A ring spring 46 is disposed between seat 44 and section 20 to resiliently stop piston 38 in a forward battery position.

A sleeve 48 fixed to stem 40 includes a flange 49 projecting into an annular cavity 50 of section 18 to form an expansible chamber 51 which is connected to a pressurized supply of nitrogen, or other inert gas (not shown), to prevent seepage of unexploded propellant along stem 40 and to dampen the forward movement of piston 38.

Stem 40 includes an extension 53, and a follower 54 splined thereto between shoulders 55 and 56 is provided with diametral rollers 57 spaced 90 degrees apart for engagement with spiral cams 58 provided in receiver 14.

An actuator 64 axially slidable in receiver 14 is provided with a cam 66 for engagement with radial rollers 68 mounted on drum 26 so as to correspond to chambers 28. Actuator 64 is rearwardly biased to a battery position by a pair of drive springs 70 to selectively retain pairs of the chambers 28 in the firing stations and the cam is disposed for the sequential rotation of successive pairs of such chambers to the firing stations responsive to operation of the actuator. A cylinder 72 secured to receiver 14 receives an axially slidable piston 74 secured to actuator 64, and an aperture 75 conducts discharge gases from barrels 15 to cylinder 72 for forward operation of piston 74 responsive to the gases.

Stem 40 is provided with four apertures 76 which communicate with corresponding holes through sleeve 48 and four radial ducts 78. Piston 38 is provided with four nozzles 80 comprising elemental depressions disposed in the rearward portion of the periphery of piston 38 and back of the apertures 76, ducts 78 and such nozzles are spaced apart 90 degrees. Nozzles 80 are angularly displaced 35 degrees from ducts 78.

Liquid propellant under pressure is supplied through a tube 79 to an annulus 81 of cylindrical aperture 25 disposed in section 18 so as to be at all times, in communication with apertures 76. Flow of the propellant to the annulus is controlled by a valve (not shown).

Valves to control flow of propellant to combustion chamber 35 include diametral grooves 82 in seat 44 and channels 84 in rearward section 22 and such grooves and channels communicate respectively with ducts 78 and nozzles 80. Propellant flow is indicated by the arrows in FIG. 1.

Cams 58 include steps 85 and 86 and rollers 57 are biased outwardly by corresponding springs 59 for engagement therewith for progression of the rollers to positions 88, 90, 92, and 94 in the sense noted in FIG. 8. When the rollers 57 are in the positions 88 or 94, ducts 78 are

aligned with grooves 82, and when in the positions 90 or 92, nozzles 80 are aligned with channels 84.

A trigger mechanism (not shown) is disposed for retention of actuator 64 in an intermediate position substantially one inch before the battery position.

In operation, the propellant valve is closed, the trigger mechanism is released and gun 12 is cycled three times by a charger (not shown) to dispose a pair of the projectiles in the charging stations. In the third cycle, actuator 64 is seared and the propellant valve is opened to permit flow of the propellant into compartment 42 and reservoir 45.

When the trigger mechanism is again released, actuator 64 proceeds to the battery position responsive to spring 70. The rearward movement of actuator 64 is converted to forward movement of follower 54 by the operative cooperation of a pinion gear 102 journaled in receiver 14 with a pair of racks 100 and 101 provided respectively on actuator 64 and a collar 104 which is slidingly mounted over extension 53 for engagement with follower 54 during rearward movement of actuator 64 under the bias of spring 70, the rollers 57 are cammingly rotated to position 90 and thereby piston 38 is rotated to register nozzles 80 with channels 84 for flow of the propellant therethrough responsive to the pressure of the propellant to begin combustion thereof in combustion chamber 35 by igniter 36.

Piston 38 moves forwardly responsive to gases from the combustion and rollers 57 engage cam 58 for rotation of the rollers to position 94 for alignment of ducts 78 with grooves 82. Piston 38 continues forwardly to force the propellant in reservoir 45 rearwardly through channel 84 and nozzles 80 into combustion chamber 35 until the propellant is exhausted from such reservoir, whereby none of the unexploded propellant remains in the reservoir to pass into the drum for discharge therein to cause damage to the gun and operating personnel.

During the forward movement, ducts 78 are blocked by the inner surface of seat 44. Near the end of the rearward stroke, cam 58 displaces rollers 57 to position 94 to cut off flow of propellant through channel 84.

Pressure on piston 38 is reduced as projectiles 30 leave barrels 15 and piston 38 is returned to the rearward position responsive to follower spring 60 and the compressed gases in chamber 51. As stem 40 moves rearwardly, ducts 78 are uncovered for flow of propellant to fill reservoir 45 for the succeeding cycle of the gun.

Projectiles 30 are propelled from chambers 28 in the firing stations through barrels 15 responsive to the discharge, and the gases therefrom are conducted to cylinder 72 through apertures 75, as the apertures are uncovered by the projectiles, for the forward operation of piston 74.

Gun 12 is provided with a feeder (not shown) to convey projectiles 30 to positions in axial alignment with loading stations of chambers 28, which are the stations occupied by those chambers next succeeding the firing station chambers. A rammer 116 secured to actuator 64 includes fingers 118 for half-ramming projectiles 30 into the next succeeding chambers and fingers 120 for finish-ramming the cartridges into the chambers succeeding the firing station chambers responsive to the rearward strokes of actuator 64.

Although a particular embodiment of the invention has been described in detail herein, it is evident that many variations may be devised within the spirit and scope thereof and the following claims are intended to include such variations.

We claim:

1. In combination with a pressurized supply of liquid propellant, an automatic gun including a receiver, a pair of barrels, a drum rotatably mounted in the receiver for simultaneously conveying projectiles to firing stations in alignment with said barrels, an actuator disposed in said receiver for longitudinal reciprocation during cyclic operation of said gun and cam means for converting the longitudinal reciprocation of said actuator to rotation of the drum, a firing device including a housing provided with an aperture including a cylindrical portion terminated by an end portion, a piston slidingly mounted in said cylindrical portion for reciprocation between a battery and a recoil position, a spring for biasing said piston to the battery position, a combustion chamber formed in said cylindrical portion between said end portion and said piston for the discharge of a metered quantity of said liquid propellant therein, said piston being disposed for actuation to the recoil position by the discharge, duct means for directing the gases from the discharge against the projectiles in the firing stations for the simultaneous propulsion thereof through said barrels, a stem portion extending from said piston along said aperture, a cylindrical seat mounted in said aperture and provided with an axial hole for slidingly receiving said stem portion, said seat being spaced from said piston when in the battery position to form a reservoir therebetween for metering a predetermined quantity of said propellant sufficient for the simultaneous propulsion of the projectiles through the barrels, said seat being engageable by said piston when in the recoil position to completely reduce said reservoir, a cylindrical compartment axially disposed in said stem portion, means for conducting propellant from the pressurized supply to said compartment, ducts extending through said stem portion from said compartment, grooves, channels and nozzles corresponding to said ducts provided respectively in said sleeve, housing and piston, a follower mounted to said stem portion for limited longitudinal movement relative thereto and rotational movement therewith, cam portions provided in the receiver for engaged cooperation with said follower for rotating said piston to align said ducts with said grooves during movement of said piston to the battery position by said spring for passage of said propellant from said compartment to fill said reservoir and to align said nozzles with said channels when said piston is in the battery position and for passing the metered quantity of said propellant from said reservoir to said combustion chamber during movement thereof to the recoil position, and means for discharging the propellant in said combustion chamber.

2. A firing device as in claim 1 with a collar inclosing said stem for engagement with said follower, a pair of racks respectively secured to said collar and the actuator and a gear journaled on the receiver for engagement therewith to displace said follower and rotate said piston for alignment of said ducts and said grooves responsive to the reciprocation of said actuator.

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April 11, 1967 E. G. DORSEY, JR., ETAL 3,313,208

LIQUID PROPELLANT FOR SMALL CALIBER GUN

Filed March 25, 1953 2 Sheets-Sheet 1

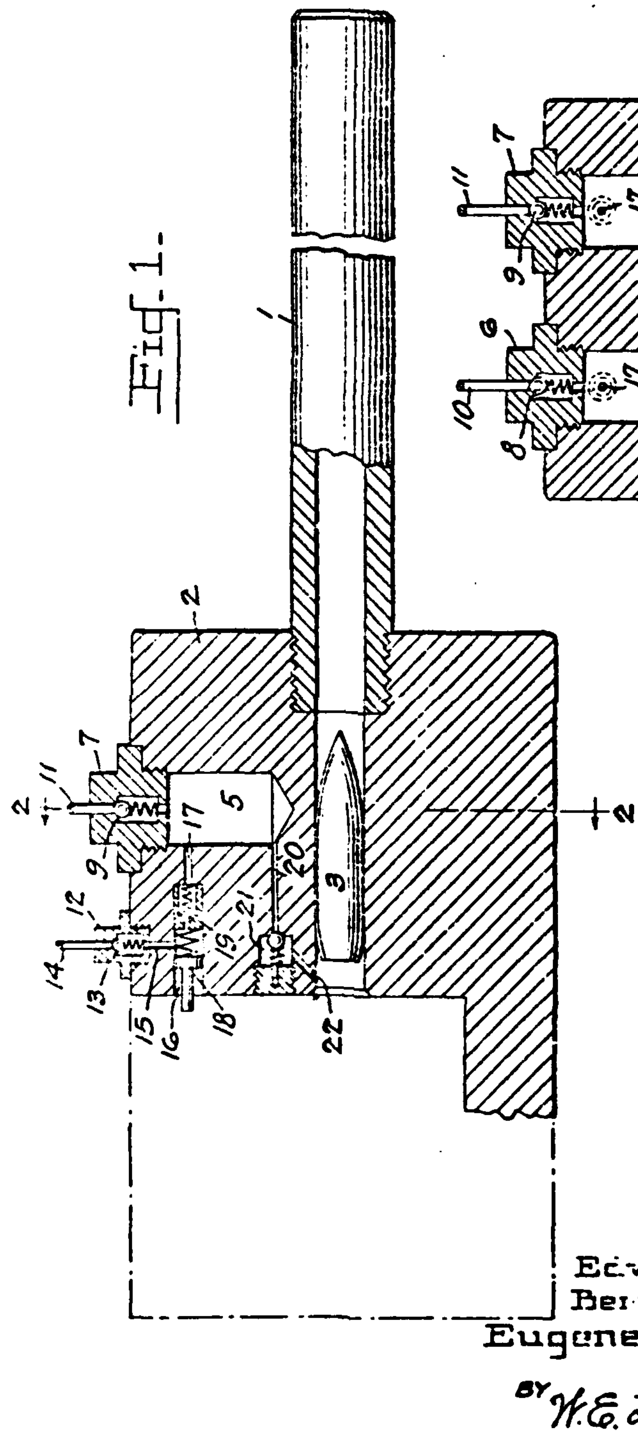

Fig. 1.

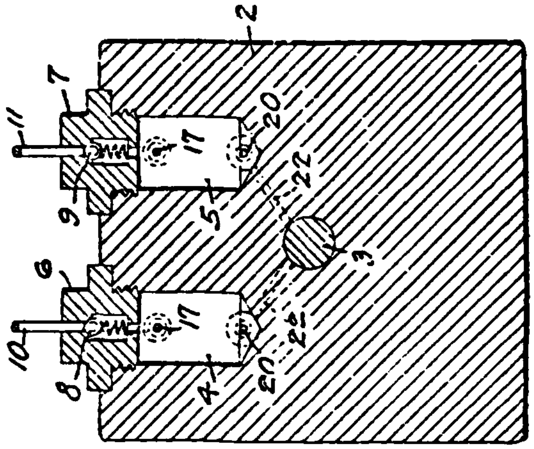

Fig. 2.

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LIQUID PROPELLANT FOR SMALL CALIBER GUN

Filed March 25, 1953 2 Sheets-Sheet 2

Fig. 3.

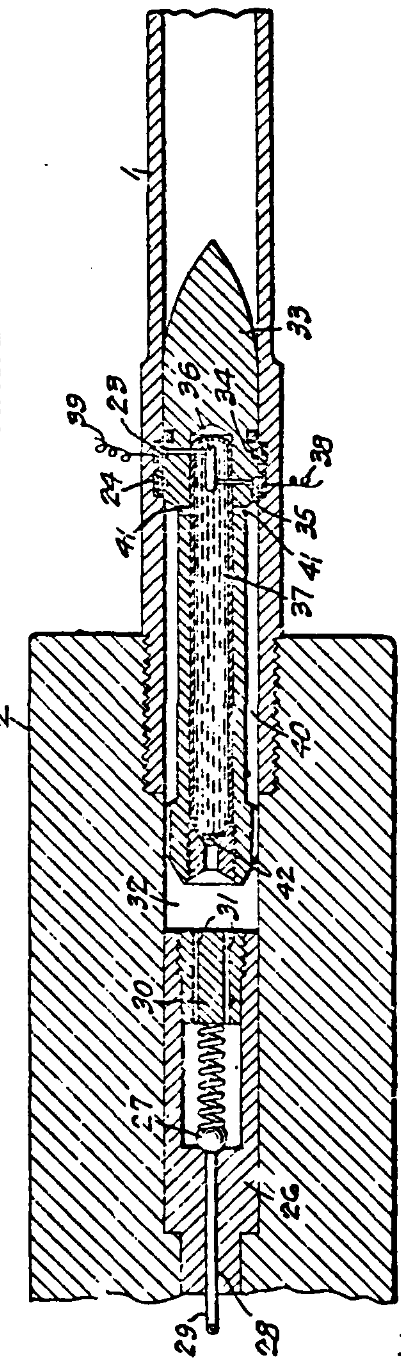
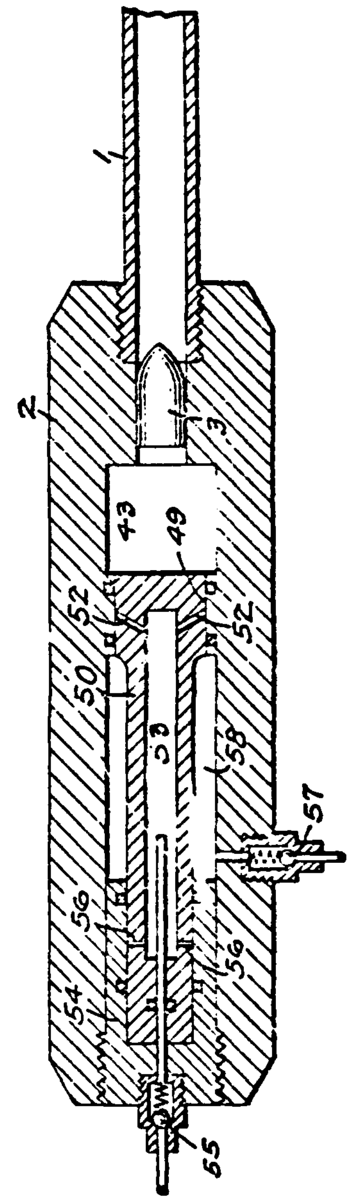


Fig. 4.



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LIQUID PROPELLANT FOR SMALL CALIBER GUN

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11 Claims. (Cl. 89—7)

This invention relates generally to ordnance, and in particular to a novel system for propelling projectiles from gun barrels or tubes.

Our invention consists of a method whereby self-igniting chemicals may be intimately intermixed so that their spontaneous reaction produces a pressure for projectile ejection and flight. It will be understood that in the specification and in the claims appended hereto the word "hypergolic" is intended to be used as defined in the Defense Department's Glossary of Guided Missile Terms, "Capable of igniting spontaneously upon contact."

It is a broad object of our invention to improve on the weapons now in use. It is a further and more particular object of our invention to provide a system for propelling projectiles in which highly reactive liquid chemicals are used in place of the usual solid propellants.

It is a still further object of our invention to provide a reactive chemical weapon which is safe to operate and reliable in use.

Other objects of the invention will be evident from the following description and the appended drawings in which:

FIGURE 1 is a fragmentary longitudinal section of a preferred embodiment of our novel weapon.

FIGURE 2 is a view taken on lines 2—2 of FIGURE 1 and looking in the direction of the arrow.

FIGURE 3 is a fragmentary longitudinal section of another species of our invention.

FIGURE 4 is a fragmentary longitudinal section of still another species of our invention.

Referring now to the drawings wherein like reference characters indicate like parts and particularly to FIGURES 1 and 2, reference character 1 indicates a gun barrel of conventional design threaded or otherwise firmly affixed to breech 2 which has a longitudinal chamber aligned with the barrel for the reception of a projectile 3. Two cavities 4 and 5, respectively, are formed in the breech as is best seen in FIGURE 2 and serve as main firing reservoirs for the several hypergolic components which constitue the propellent charge. The volumes of the cavities can be selected as propellant metering devices. Plugs 6 and 7 are threaded into the several cavities and serve to contain spring loaded ball valves 8 and 9 substantially as shown. Pipes 10 and 11 connect the valves with the main storage tanks for the hypergolic fluids (not shown). A pilot or triggering feed system is connected to each of the firing reservoirs 4 and 5 for a purpose that will presently appear. As is revealed in FIGURE 1 an auxiliary plug 12 is threaded into block 2 and contains a spring loaded valve 13 closing the end of pipe 14 which is joined to pipe 10 or otherwise connected to the main storage tank holding the reactant fluid that normally is led into reservoir 4. A passage 15 extends downward from the plug and connects with a chamber 16 extending normal thereto and having a narrow portion 17 opening into reservoir 5. A spring loaded piston 18 and rod adapted for external actuation are slidably received within chamber 16 and the forward motion of piston 18 is arrested by spring loaded ball valve assembly 19. From a point at or near the bottom of reservoir 5 extends bore 20 leading through valve assembly chamber 21 to passage 22 which opens into the rearward portion of the projectile receiving chamber. It will be understood that an indentical pilot feed system (not shown) is provided for reservoir 4.

In operation two reactive fluids which may be called fuel and oxidant and can be for example, hydrazine with hydrogen peroxide, or hydrazine with nitric acid are separately stored in their respective external tanks. One reactant is pumped into reservoir 4 and the other into reservoir 5 until they are full whereupon the spring loaded valves effectively seal the fluid therein. The pumping pressure also forces a minute amount of the reactants into the opposed pilot feed systems so that reservoir 5 may hold the fuel and the pilot system connected thereto will hold the oxidant while reservoir 4 holds the oxidant and its pilot system contains a small amount of fuel. Triggering of the firing cycle is accomplished by moving the two pilot pistons forward by any suitable mechanical or electrical means. This motion forces the pilot fuel through the valves and into the firing reservoirs whereby a chemical reaction takes place accompanied by emission of heat and pressure limited only by the amount of pilot fluid injected. The pressure built up by the reaction forces the fluids down their respective passages and into a combustion chamber behind the projectile. When the main hypergolic fluids meet in the chamber a violent reaction takes place whereby the projectile is forced down the barrel and started on its trajectory.

Our invention is not of course limited to the specific examples of fuel and oxidant enumerated above but contemplates the utilization of any and all substances and compounds that react spontaneously and violently upon contact including a monopropellant such as nitro-methane or methyl acetylene with a catalyst.

An important variant of our invention is revealed in FIGURE 3 wherein reference character 1 indicates the gun barrel having annular contact members 23, 24, and 2 is the breech. A longitudinal passage in the breech receives a housing 26 having a cavity therein to hold spring valve 27 adapted to yieldingly close bore 28 which is connected by pipe 29 to a storage tank. A plug 30 is threadedly held in the housing and has formed therein passages 31 leading to a combustion chamber 32 formed immediately to the rear of a projectile indicated generally as 33.

The projectile, which will now be described, has annular rings 34 and 35 secured thereto adapted to engage contact members 23 and 24 substantially as shown. A squib 36 is housed within the aforesaid parts of an inner chamber 37 and is electrically connected to an external source of electrical energy through leads 38 and 39. The middle portion of the projectile is of a reduced diameter whereby an annular volume 40 is formed. Frangible plugs 41 are held in holes communicating between inner chamber 37 and volume 40 and a frangible disc 42 is held at the rear portion of the chamber substantially as shown. It is intended to pre-load the projectile with one of the reactants (usually a fuel) which completely fills the internal chamber 37 and is in intimate contact with the squib housed therein.

In operation the preloaded projectile is inserted by means not shown, into the firing position in the weapon and the other reactant is admitted under pressure from pipe 29 through passages 31 and into chamber 32 whereupon it fills volume 40 and completely surrounds the preloaded reactant. When the squib is fired by external triggering means the frangible plugs 41 are shattered and the several reactants mix at the head of the fuel and oxidant columns. The pressure thus generated results in expulsion of the components to the rear and into the combustion chamber where they mix and a violent reaction takes place to expel the projectile. After the discharge another projectile may be rapidly inserted by automatic means if desired to complete the cycle and ready the gun for another round.

A still further variant of our invention is illustrated in FIGURE 4 wherein breech block 2 has a longitudinal passage therethrough to receive at the forward end thereof of barrel 1. A projectile 3 is frictionally held aligned with the barrel for motion therein when the pressure in chamber 43 reaches a predetermined value. The breech block passage has a portion of reduced diameter 49 to slidably receive the enlarged head of hollow piston 50. Passages 52 radiate from the internal cavity 53 to the outer periphery of the piston head and passages 56 lead from the internal cavity radially outward for a purpose that will presently be explained. A plug 54 is threaded into the rear end of the passage and serves to receive spring loaded valve 55 and to act as a lateral guide during piston motion. A spring loaded valve 57 is threaded into the breech block and leads into the annular volume 58 formed between the piston and the block.

In operation one of the reactants for example an oxidant is pumped from a storage tank and forced through valve 55 to fill the volume 53. The other reactant is pumped from its tank and forced through valve 57 to fill volume 58. The gun is triggered by moving piston 50 forward by any suitable mechanical or electrical system whereby passages 52 open into chamber 43, volume 58 is opened into chamber 43 around the piston and passages 56 connect volumes 53 and 58. A minute quantity of the reactants will move through the passages 56 and a chemical reaction accompanied by a pressure rise occurs in the area adjacent the passages. This pressure forces the contents of volume 58 forward around the piston and into chamber 43 and the contents of volume 53 through passage 52 into chamber 43 where the reactants mix and expel the projectile.

In a general manner, while we have, in the above description disclosed what we deem to be practical and efficient embodiment of the present invention, it should be well understood that we do not wish to be limited thereto as there might be changes made in the arrangement, disposition and form of the parts without departing from the principle of the present invention as comprehended within the scope of the accompanying claims.

What we claim is:

1. A gun comprising a breech casing, a barrel affixed to said casing, a projectile in said casing and aligned with the said barrel, a propellant comprising an oxidant and a fuel, said oxidant and said fuel contained in separate chambers formed in said gun, means including a passage to admit a predetermined quantity of fuel into the oxidant chamber, a passage to admit a quantity of oxidant into the fuel chamber to pressurize each said fuel and oxidant chambers, and means forming passages from the chambers to intermingle the said oxidant and the said fuel behind the said projectile and detonate spontaneously.

2. A firearm comprising in combination a breech casing, a barrel affixed to the said casing, a projectile in said casing and aligned with said barrel, a combustion chamber, a propellant to expel said projectile, said propellant comprising an oxidant and a fuel, an elongated hollow member longitudinally movable within said casing, said oxidant contained in a first chamber within said hollow member, said fuel contained in a second annular chamber in said casing surrounding said hollow member between said member and said casing, means forming a plurality of passages at the rear of said member, means forming a plurality of passages at the front of said member whereby movement of said member in a direction toward the said barrel joins the said first and second chambers at the rear thereof to effect a limited expansion in both chambers to expel the fuel and the said oxidant into the said combustion chamber.

3. A firearm comprising in combination a breech casing a barrel affixed to the said casing, a projectile in said casing and aligned with said barrel, a combustion chamber in said casing, a propellant comprising an oxidant and a fuel, an elongated member longitudinally movable within said casing, said oxidant contained in a first chamber within said member, said fuel contained in a second annular chamber formed between said member and said casing, means forming a plurality of passages at the rear of said member, means forming a plurality of passages at the front of said member whereby movement of said member in a direction toward the said barrel joins the said first and second chambers for pressurization thereof and expulsion of the fuel and oxidant into the said combustion chamber.

4. A firearm comprising in combination a breech casing, a barrel affixed to said casing, a projectile in said casing and aligned with said barrel, a combustion chamber, a propellant to expel said projectile, said propellant comprising an oxidant and a fuel, an elongated hollow member axially movable within said casing, said oxidant contained in a first chamber within said hollow member, said fuel contained in a second annular chamber in said casing surrounding said hollow member, means forming a plurality of normally closed passages at the rear end of said hollow member whereby axial movement of said hollow member in a direction toward said barrel uncovers the rear passages for effecting a limited degree of intermingling of oxidant and fuel to pressurize both chambers, and means comprising a plurality of normally closed passages at the front end of said hollow member whereby the oxidant is forced from its chamber through said front passages under said internally developed pressure and simultaneously fuel is forced from its chamber to pass said hollow member to intermingle with the fuel in the combustion chamber and detonate therein spontaneously.

5. A liquid propellant gun comprising a breech casing, a barrel affixed to said casing, a projectile in said casing aligned with said barrel, a combustion chamber in said casing behind said projectile, a hypergolic propellant comprising an oxidant and a fuel contained in separate chambers in said gun, injection means adapted to admit a predetermined quantity of fuel into said oxidant chamber and a predetermined quantity of oxidant into said fuel chamber to pressurize each said fuel and oxidant chambers, and passages between each said fuel and oxidant chamber and said combustion chamber.

6. A gun comprising a breech casing, a barrel affixed to said casing, a combustion chamber in said casing communicating with said barrel, a fuel chamber in said casing containing a hypergolic fuel, an oxidant chamber in said casing containing a hypergolic oxidant, pressurizing means operatively associated with said fuel and oxidant chambers, said pressurizing means injecting a predetermined quantity of fuel into said oxidant chamber and a predetermined quantity of oxidant into said fuel chamber to pressurize each said fuel and oxidant chamber, and passages connecting said fuel and oxidant chambers to said combustion chamber whereby the fuel and oxidant are forceably intermixed in said combustion chamber.

7. In a hypergolic propellant gun a breech casing, a plurality of firing reservoirs in said breech, an oxidant in half of said reservoirs and a fuel in the remainder of said reservoirs, a triggering feed system for said reservoirs to expel the said oxidant and fuel therefrom under pressure, said system comprising a fuel chamber having passages connected with said oxidant reservoirs, an oxidant chamber having passages connected with said fuel reservoirs and means to discharge the fuel and oxidant in said chambers into said reservoirs, and passage means to conduct said fuel and oxidant in said reservoirs to a combustion chamber for spontaneous combustion therein.

8. A liquid propellant firearm comprising a breech casing, a barrel affixed to said breech casing, a projectile in said casing aligned with said barrel, a hypergolic propellant comprising an oxidant and a fuel, separate reservoirs, one of which is within said projectile, containing predetermined quantities of said oxidant and said fuel, means to intermix said predetermined quantities of said

oxidant and said fuel in a combustion chamber including a first passage connecting said oxidant reservoir with said combustion chamber and a second passage connecting said fuel reservoir with said combustion chamber, normally closed conduit means associated with the reservoir in said projectile and the other said reservoir to connect said fuel reservoir with a source of said oxidant and said oxidant reservoir with a source of said fuel, triggering means initiated on firing of said gun to open said normally closed conduits and allow intermixing of a small quantity of fuel and oxidant to pressurize said fuel and oxidant reservoirs and force the predetermined quantities of said oxidant and said fuel through said first and second passages into said combustion chamber.

9. The firearm as in claim 8 wherein said fuel chamber is formed in said projectile and said oxidant chamber is formed in said casing concentric with said fuel chamber in said projectile.

10. The firearm as in claim 8 wherein said fuel chamber is formed in said projectile and said oxidant chamber is formed concentric with said projectile and between said projectile and said casing when said projectile is in said casing.

11. A liquid propellant gun comprising a breech casing, a barrel affixed to said casing, a projectile in said casing aligned with said barrel, a hypergolic propellant comprising an oxidant and a fuel, separate reservoirs containing predetermined quantities of said oxidant and said fuel, means to intermix said predetermined quantities of said oxidant and said fuel in a combustion chamber including a first passage connecting said oxidant reservoir with said combustion chamber and a second passage connecting said fuel reservoir with said combustion chamber, normally closed conduit means associated with said oxidant and said fuel reservoirs to connect said fuel reservoir with a source of oxidant and said oxidant reservoir with a source of said fuel, means initiated on firing said gun to open said normally closed conduits and allow intermixing of a small quantity of fuel and oxidant to pressurize said oxidant reservoir and said fuel reservoir and force said predetermined quantities of said oxidant and said fuel through said first and second passages for intermingling and spontaneous ignition in said combustion chamber.

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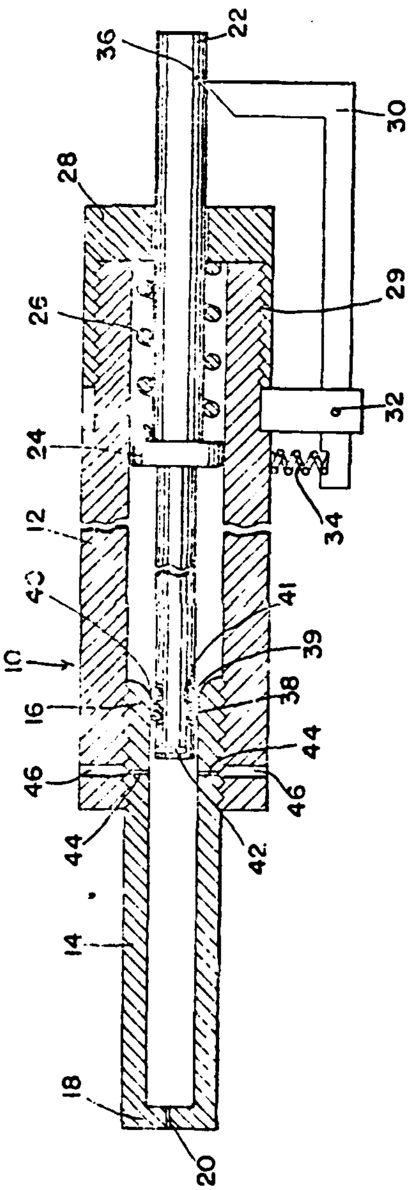
Jan. 30, 1968 J. J. SCANLON, JR 3,366,058

IGNITION DEVICE FOR LIQUID PRIMERS

Filed Oct. 19, 1965



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United States Patent Office

3,366,058
Patented Jan. 30, 1968

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3,366,058
IGNITION DEVICE FOR LIQUID PRIMERS

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Filed Oct. 19, 1965, Ser. No. 498,161
3 Claims. (Cl. 102—70)

ABSTRACT OF THE DISCLOSURE

An ignition device consisting of a combustion chamber, secured in a housing; a piston operative within the housing and combustion chamber to ignite a liquid propellant and expel a flame through a small hole in the combustion chamber.

The invention described herein may be manufactured and used by or for the Government for governmental purposes without the payment to me of any royalty thereon.

Since the advent of caseless ammunition the need for a clean, combustible primer has been ever present. During repetitive firing the solid particles in the conventional lead styphnate mix, such as antimony sulfide, would collect on the seal area and on the firing pin and cause deterioration thereof.

The invention consists of a device that can ignite alkyl nitrate liquid propellants and expel a flame through a small hole.

Therefore, the object of the present invention is the provision of an ignition device using a completely gaseous primer.

Another object is to provide an ignition device that does not require the use of a firing pin.

The above objects as well as others together with the benefits and advantages of the invention will be apparent upon reference to the detailed description set forth below, particularly when taken in conjunction with the drawing annexed hereto in which there is shown an ignition device 10, consisting of a cylindrical housing 12 and a combustion chamber 14. The combustion chamber 14 has an open end 16 extending into said housing and a closed end 18 extending outward therefrom. Said closed end 18 has an axial vent hole 20 therein. A piston 22 is provided extending through both the housing 12 and the combustion chamber 14. Said piston is of a diameter slightly smaller than the combustion chamber diameter and has a radial projection 24, the diameter of which is slightly smaller than the housing diameter. A spring or resilient means 26 is provided at the rear of said housing 12 between said projection 24 and a cap 28. Said cap 28 is secured to said housing by screw threads 29. A catch means or sear 30 is provided pivotally attached at 32 to housing 12. The sear 30 is biased by resilient means or spring 34 to remain engaged with a notch 36 in piston 22. The forward end of the piston 22 is provided with a high pressure seal consisting of metal rings 38 and 39, secured in radial grooves 40 and 41. Between the groove 40 and the tip of the piston is a vapor pocket 42. Inlet ports 44 and 46 are provided in the combustion chamber 14 and the housing 12, respectively. When the piston 22 is in the cocked position, as shown in the drawing, the inlet ports 44 and 46 are located a short distance in front of the tip thereof.

In operation, an alkyl nitrate liquid propellant such as ethyl nitrate is injected into the inlet ports 44 and 46. The sear 30 is pulled down against the action of the spring 34 thereby releasing the piston 22 through the action of the spring 26. The piston 22 travels forward compressing the vapor of the liquid propellant in the vapor pocket 42. As the pressure in the vapor pocket 42 builds up, the temperature increases. When a temperature of 450° F. is reached the vapor in said vapor pocket 42 ignites thereby igniting the remaining liquid in the combustion chamber 14 and the liquid that is escaping through the vent hole 20. The liquid escaping through the vent hole 20 ignites the caseless cartridge (not shown) or the like which is placed directly in front of said vent hole 20. The flame which is produced at the vent hole 20 reaches 3000° F.

For example, the utilization of a vapor pocket of 0.062", a vent hole of 0.013", a combustion chamber bore of 0.250", and a 15 lb. spring will yield a piston stroke of 2.50".

The piston stroke can be decreased by merely reducing the diameter of the vapor pocket.

Obviously many modifications and variations of the present invention are possible in light of the above teachings. It is therefore to be understood, that within the scope of the appended claims, the invention may be practiced otherwise than as specifically described.

I claim:

1. An ignition device comprising a housing, a combustion chamber having an open end extending into said housing, and a closed end extending outward therefrom, said closed end having a vent means therein, said combustion chamber having inlet means coinciding with inlet means in said housing, said inlet means provided for the insertion of a liquid propellant, a piston extending through said housing and said combustion chamber, said piston defining a cylindrically shaped vapor pocket, located radially within said piston immediately rearwardly of the forward end thereof and being located before ignition immediately behind said inlet means so as to be able to collect the vapor therefrom during its passage through said chamber, a first resilient means located in the rear portion of said housing abutting a projection means on said piston and a cap secured to the end of said housing, a catch means pivotally attached at one end to said housing, the other end of said catch means engaging a holding means in said piston thereby holding said piston in a cocked position, said catch means being biased into said holding means by a second resilient means on the side of said housing.

2. A device of the type described in claim 1, wherein said piston has a plurality of grooves in the vicinity of its forward end, said grooves containing high pressure seals.

3. An ignition device comprising a cylindrical housing, a combustion chamber having an open end extending into said housing, and a closed end extending outward therefrom, said closed end having a vent hole therein, said combustion chamber having inlet ports coinciding with inlet ports in said housing, said inlet ports provided for the insertion of an alkyl nitrate liquid propellant, a piston extending through said housing and said combustion chamber, said piston defining a cylindrically shaped vapor pocket, located radially within said piston immediately rearwardly of the forward end thereof and being located before ignition immediately behind said inlet means so as to be able to collect the vapor therefrom during its passage through said chamber, a first spring means located

in the rear portion of said housing abutting a radial projection on said piston and a cap secured to the end of said housing, a sear pivotally attached at one end to said housing, the other end of said sear engaging a notch in said piston thereby holding said piston in a cocked position, said sear being biased into said notch by a second spring means on the side of said housing.

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U.S. NAVY PATENTS

Patent Number: 3,712,171
Author: Jon L. Sweigart, Fredericksburg, VA
Title: Spring Actuated Liquid Propellant Gun System
Date: January 23, 1973

Patent Number: 4,005,632
Author: John W. Holtrop, Ridgecrest, CA
Title: Liquid Propellant Gun
Date: February 1, 1977

Patent Number: 4,033,224
Author: John W. Holtrop, Ridgecrest, CA
Title: Liquid Propellant Gun
Date: July 5, 1977

Patent Number: 4,091,711
Author: Gary L. Petersen, Ridgecrest, CA; John W. Holtrop, Ridgecrest, CA
Title: Rotary Bolt Liquid Propellant Gun
Date: May 30, 1978

Patent Number: 4,160,405
Author: Steven E. Ayler, China Lake, CA; John W. Holtrop, Ridgecrest, CA
Title: Liquid Propellant Gun, Positive Displacement Single Valve
Date: July 10, 1979

Patent Number: 4,170,922
Author: Gary L. Petersen, Ridgecrest, CA; Larry L. Liedtke, Ridgecrest, CA
Title: Ignitor
Date: October 16, 1979

Patent Number: 4,172,408
Author: Steve Ayler, China Lake, CA; John Holtrop, Ridgecrest, CA;
Bruce Bartels, Ridgecrest, CA
Title: Liquid Propellant Gun, Breech Pressure Axial Injection
Date: October 30, 1979

United States Patent [19]

Sweigart

[11] **3,712,171**

[45] **Jan. 23, 1973**

[54] **SPRING ACTUATED LIQUID PROPELLANT GUN SYSTEM**

[75] Inventor: **Jon L. Sweigart**, Fredericksburg, Va.

[73] Assignee: The United States of America as represented by the Secretary of the Navy

[22] Filed: **Nov. 16, 1970**

[21] Appl. No.: **89,740**

[52] **U.S. Cl.** ....89/7, 60/26.1, 60/39.74 R

[51] **Int. Cl.** F41f 1/04

[58] **Field of Search** 89/7, 8, 1; 60/39.46, 39.48, 60/39.79, 26.1

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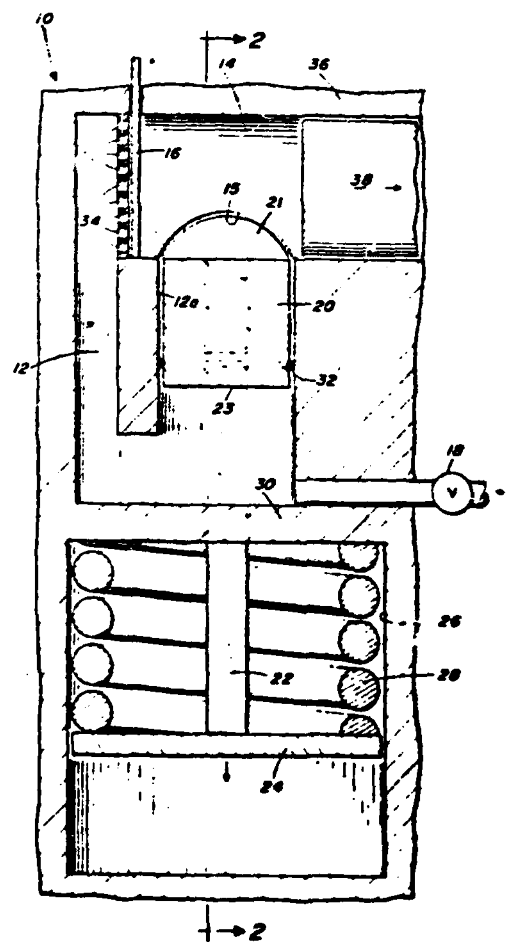
Primary Examiner—Samuel W. Engle

Attorney—R. S. Sciascia and Thomas O. Watson, Jr.

[57] **ABSTRACT**

A gun system employs liquid oxidizers and fuels instead of the conventional solid propellants. To start a cycle, a propellant chamber is pressurized with liquid propellant to 5,000 PSI. The fluid pressure actuates a piston which is movable within the propellant chamber to automatically compress a spring. The piston is provided with commercial O-ring seals that are capable of withstanding the 5,000 PSI and seal the only opening in the propellant chamber. After pressurization a quick-acting valve is opened, and the spring-biased piston forces the liquid propellant through nozzles and into a combustion chamber where the ensuring combustion launches a projectile. Since the pressure in the combustion chamber equalizes with the pressure in the propellant chamber, the maximum pressure applied to the seals is the 5,000 PSI spring pressure.

9 Claims, 3 Drawing Figures



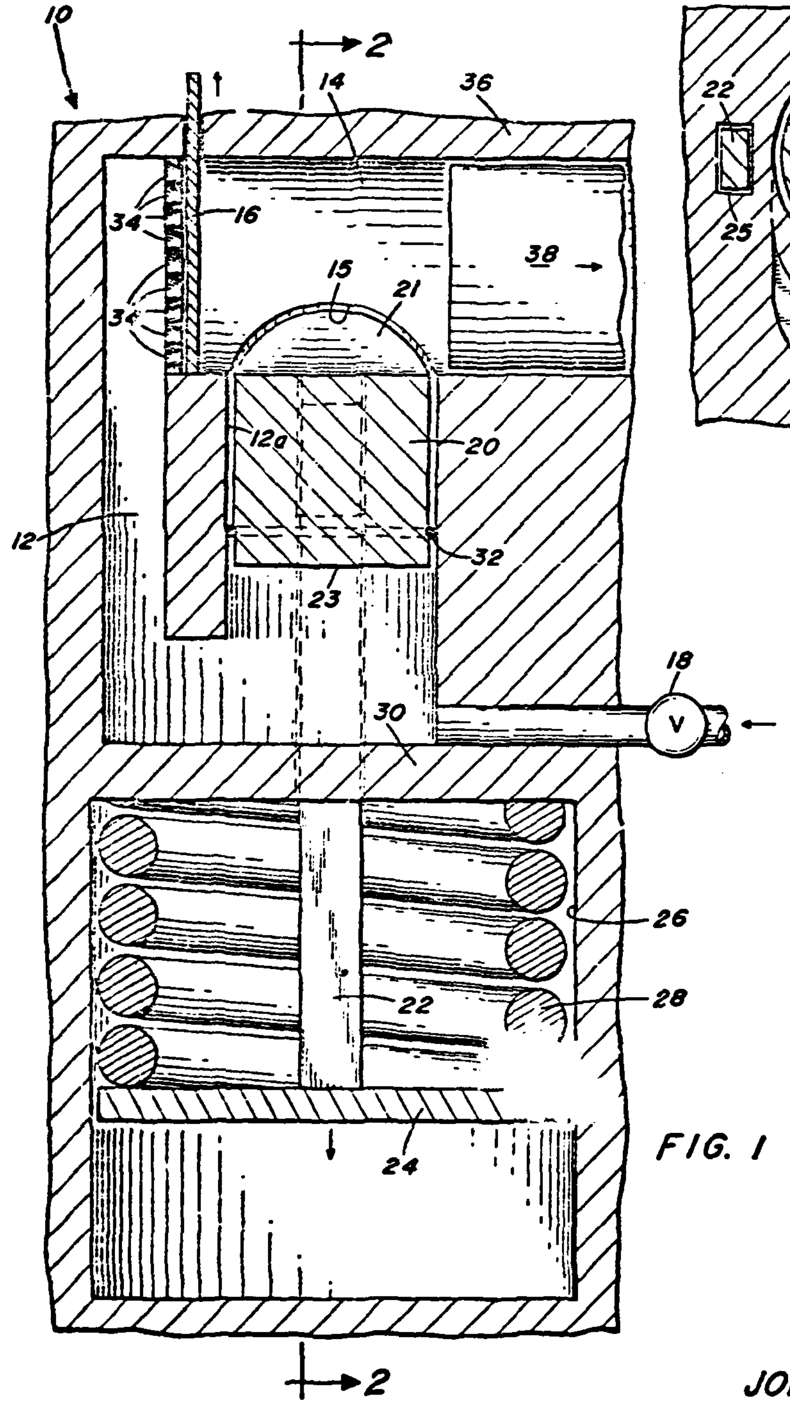


FIG. 1

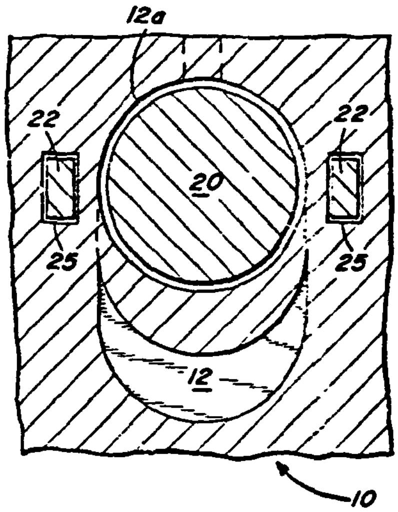


FIG. 3

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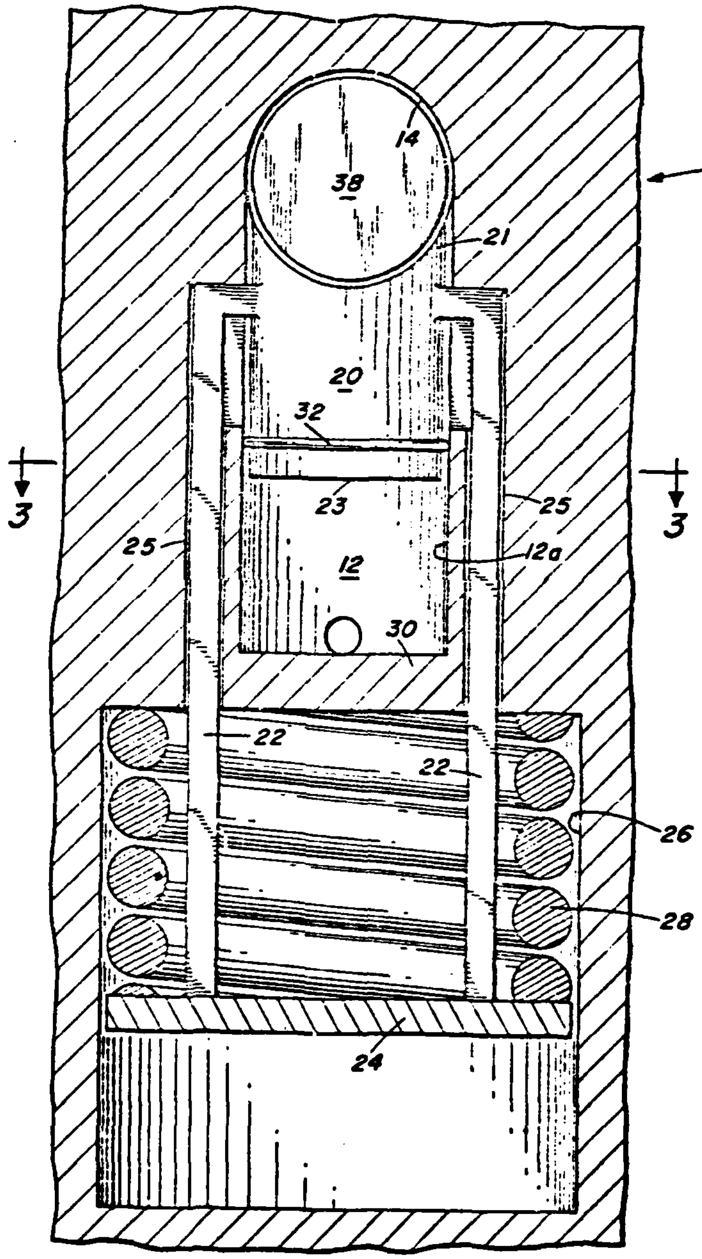

FIG. 2

SPRING ACTUATED LIQUID PROPELLANT GUN SYSTEM

STATEMENT OF GOVERNMENT INTEREST

The invention described herein may be manufactured and used by or for the Government of the United States of America for governmental purposes without the payment of any royalties thereon or therefor.

BACKGROUND oF THE INVENTION

The present invention relates generally to improvements in propellant gun systems, and more particularly it pertains to a new and improved spring-actuated liquid propellant gun system wherein the maximum pressure the piston seals will be subjected to is the spring pressure rather than the full pressure produced in the combustion chamber.

In the prior art, liquid propellant guns have been designed using the differential piston technique. Such devices have been unsatisfactory as the O-ring seals are required to seal the full combustion chamber pressure. However, commercial O-ring piston seals are only capable of handling up to 5,000 PSI and therefore cannot withstand the full chamber pressure to which they are subjected. Another problem in the prior art has been the difficulty in providing a sustained pressure during the projectiles internal ballistic path. In operation, as the projectile moves down the gun tube, the volume of the combustion chamber increases, thereby decreasing the overall pressure applied to the projectile.

OBJECTS OF THE INVENTION

Accordingly, it is an object of the present invention to provide a liquid propellant gun system wherein the seals are required to withstand only 5,000 PSI spring pressure.

Another object is the provision of an increased mass flow of propellant to enter the combustion chamber as the projectile moves down the gun tube whereby the pressure driving said projectile is maintained substantially constant.

A further object of the invention is to provide greater gas pressure behind the projectile during its internal ballistic path.

SUMMARY OF THE INVENTION

The general purpose of this invention is to provide a spring-actuated liquid propellant gun system which uses liquid oxidizers and fuels instead of the conventional solid propellants normally employed in propellant gun design. To start the cycle, a propellant chamber is pressurized with liquid propellant to 5,000 PSI. The fluid pressure actuates a piston movable within the propellant chamber to automatically compress a spring. The piston is provided with commercial O-ring seals that are capable of withstanding the 5,000 PSI and seal the only opening in the propellant chamber. After pressurization a quick-acting valve is opened and the spring-biased piston forces the liquid propellant through nozzles and into a combustion chamber where the ensuing combustion launches a projectile. At emission of the projectile the quick-acting valve is closed and the cycle is complete.

Due to the arrangement of the combustion chamber and the propellant chamber, when combustion ensues, the pressure produced is applied to the forward end of the piston as well as through the propellant chamber to the aft end of said piston. In this manner, equal and opposite combustion pressures are applied to the piston and seals. Thus, the resultant driving force and the only net force applied to the piston seals is that produced by the spring.

Moreover, as a result of the force the spring-biased piston applies, the system provides an increasing mass flow of propellant to enter the combustion chamber as the projectile moves down the gun tube. This enables the gas pressure behind the projectile to remain substantially constant during its internal ballistic path.

Other objects, advantages and novel features of the invention will become apparent from the following detailed description of the invention when considered in conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 shows a cross section of a preferred embodiment of the spring-actuated liquid propellant gun;

FIG. 2 illustrates a section of the device taken on the line 2—2 of FIG. 1 looking in the direction of the arrows; and

FIG. 3 shows a section of the device taken on line 3—3 of FIG. 2 looking in the direction of the arrows.

DESCRIPTION OF THE PREFERRED EMBODIMENT

FIG. 1, which illustrates a preferred embodiment of the liquid propellant gun, shows an assembly 10 having an elliptical propellant chamber 12 and a cylindrical combustion chamber 14. A suitable quick-acting valve 16, such as a gate valve, separates chambers 12 and 14. Valve 16 may be mechanically operated, as by a spring (not shown), or electrically operated, as by a solenoid (not shown). With valve 16 closed, liquid propellant is pumped into propellant chamber 12 through a suitable valve 18.

A piston 20 is slidingly mounted within a bore 12*a* for reciprocation between propellant chamber 12 and combustion chamber 14. A hole 15 is provided in combustion chamber 14 to receive piston 20. As seen in FIG. 2, piston 20 is provided with a concave head or face 21. This is by way of example only, as the piston head may have other shapes, such as flat or spherical. The pressurized propellant applies a force to the aft end 23 of piston 20 to move it through hole 15 and into combustion chamber 14. The piston 20 is fixedly attached to two L-shaped connecting rods 22 (see FIG. 2) which reciprocate in paths 25 outside of propellant chamber 12. A circular plate 24 is mounted at the other end of connecting rods 22. Connecting rods 22 and plate 24 are mounted to reciprocate in a driving chamber within a cylindrical housing 26 and thereby compress a spring 28 against wall 30 of housing 26. Spring 28 is supported by plate 24 and is situated below piston 20 in the separate housing 26 because of its size and to prevent exposure of the spring to chamber temperature and gases. Commercial O-ring seals 32 are mounted on piston 20 and are capable of withstanding the 5,000 PSI to which the propellant chamber 12 is subjected to.

As seen in FIG. 1, a suitable inlet means, such as nozzles 34, are provided to allow the liquid propellant in propellant chamber 12 to enter combustion chamber 14, when gate valve 16 is opened. Nozzles 34 provide the necessary propellant injection into combustion chamber 14. Combustion chamber 14 is adjacent to and opens into a gun tube 36 in which the projectile 38 to be launched is located.

In operation, to start a cycle, gate valve 16 is closed and liquid propellant is pumped into propellant chamber 12, under pressure, via valve 18. This applies a pressure of 5,000 PSI to the aft face 23 of piston 20 to actuate it in a forward direction, into combustion chamber 14, and thereby automatically compress spring 28. (Or, of course, in the alternative, spring 28 may be mechanically compressed and liquid propellant then pumped into propellant chamber 12.) After propellant chamber 12 has been pressurized to 5,000 PSI and spring 28 compressed, gate valve 16 is opened. This causes spring 28 to expand and thereby actuate piston 20 in an aft direction to force the pressurized liquid propellant through nozzles 34. As liquid propellant enters combustion chamber 14, the combustion cycle starts. If a monopropellant is used, an igniter (not shown) is inserted in combustion chamber 14. If a hypergolic mixture of an oxidizer and fuel is used, a piston system for each could be used with combustion starting at the first contact of the two fluids.

As a result of the propellant being forced into combustion chamber 14 by the recoil of piston 20, the pressure in combustion chamber 14 equalizes with the pressure in propellant chamber 12. In addition, the pressure produced as a result of combustion is transmitted through the propellant in chamber 12 and applied to the aft face 23 of piston 20 as well as being directly applied to the forward face 21 of piston 20. In this manner, equal and opposite pressures are applied to piston 20 and seal 32 since the projected areas of the forward and aft faces are equal. Thus, the resultant driving force and the only net force being applied to seals 32 is the 5,000 PSI produced by the compression of spring 28. The explosive pressure of the combustion process forces projectile 38 out of gun tube 36. At emission of projectile 38, gate valve 16 is closed, thus stopping the cycle.

As a result of spring-loaded piston 20 forcing the pressurized fluid through nozzles 34, it is seen how the invention provides an increasing mass flow of propellant to enter combustion chamber 14 as projectile 38 moves down gun tube 36. The pressure produced by the combustion process is distributed over the continually increasing volume of combustion chamber 14 as the projectile 38 moves down gun tube 36. This increase in volume would normally decrease the effective pressure being applied to projectile 38. However, in the present invention, the increased flow of propellant being forced into combustion chamber 14 by piston 20, maintains a constant pressure in the combustion chamber as its volume increases whereby the effective pressure being applied to projectile 38 is maintained substantially constant during its internal ballistic path.

One criterion for the liquid propellant gun to function properly is that the nozzle area 34 must be equal to the area of the piston 20. This enables the spring 28 to move at its maximum velocity and increase the velocity of piston 20, which increases the mass flow of the propellant entering combustion chamber 14 as the projectile 38 moves down gun tube 36.

Obviously many modifications and variations of the present invention are possible in the light of the above teachings.

What is claimed is:

1. A liquid propellant gun system comprising:

a housing having a combustion chamber, at least one propellant chamber and at least one driving chamber therein;

a first passageway in said housing connecting said combustion chamber and a first propellant chamber;

a first piston slidingly and sealingly mounted within said first passageway;

said first piston having a forward face exposed to pressure within said combustion chamber and an aft face exposed to pressure within said first propellant chamber, said forward face and said aft face having equal projected areas;

first biasing means within a first driving chamber connected to said first piston for normally biasing said first piston away from said combustion chamber;

first means to force said first piston toward said combustion chamber against the force of said first biasing means;

a second passageway in said housing communicating with said first propellant chamber and said combustion chamber;

first valve means for controlling communication through said second passageway of said first propellant chamber and said combustion chamber; and

a gun tube extending from said combustion chamber.

2. The gun system of claim 1 wherein said first piston has an o-ring seal thereon.

3. The gun system of claim 1 wherein said first biasing means comprises a plate connected to said first piston and movable within said first driving chamber and a spring means for normally biasing said plate away from said combustion chamber.

4. The gun system of claim 3 wherein said first valve means comprises nozzle means to provide injection of a propellant into said combustion chamber and a gate valve to control flow through said nozzle means.

5. The gun system of claim 4 wherein said first means comprises the pressurized propellant within said first propellant chamber.

6. The gun system of claim 4 wherein said first means comprises mechanical means to compress said first biasing means.

7. The gun system of claim 4 wherein L-shaped connecting rods connect said plate to said first piston.

8. The gun system of claim 1 wherein a third passageway connects a second propellant chamber with said combustion chamber;

a second piston slidably and sealingly mounted within said third passageway, having an upper face exposed to pressure within said combustion chamber and a lower face exposed to pressure within said second propellant chamber;

a second driving chamber having second biasing means therein connected to said second piston for

normally biasing said second piston away from said combustion chamber;

second means to force said second piston towards said combustion chamber against the force of said second biasing means;

a fourth passageway in said housing communicating with said second propellant chamber and said combustion chamber; and

second valve means for controlling communication through said fourth passageway of said second propellant chamber and said combustion chamber.

9. A liquid propellant power plant which comprises:

a housing having a combustion chamber, at least one propellant chamber and at least one driving chamber therein;

a first passage and a second passage both connecting said propellant chamber with said combustion chamber;

a piston slidingly and sealingly mounted within said first passage having a forward face exposed to pressure in the combustion chamber and an aft face exposed to pressure in said propellant chamber;

said forward face and said aft face having equal projected areas;

biasing means connected to said piston for normally urging said piston away from said combustion chamber;

nozzle means within said second passage to provide injection of a propellant from said propellant chamber into said combustion chamber;

valve means to control the flow of propellant through said nozzle means; and

means for urging said piston toward said combustion chamber.

* * * * *

United States Patent [19]

Holtrop

[11] **4,005,632**

[45] **Feb. 1, 1977**

[54] **LIQUID PROPELLANT GUN**

[75] Inventor: **John W. Holtrop,** Ridgecrest, Calif.

[73] Assignee: **The United States of America as represented by the Secretary of the** Navy, Washington, D.C.

[22] Filed: **Sept. 15, 1975**

[21] Appl. No.: **613,690**

[52] **U.S. Cl.** **89/7;** 89/24

[51] **Int. Cl.²** **F41F 1/04**

[58] **Field of Search** .... 89/7, 24, 4 B

[56] **References Cited**

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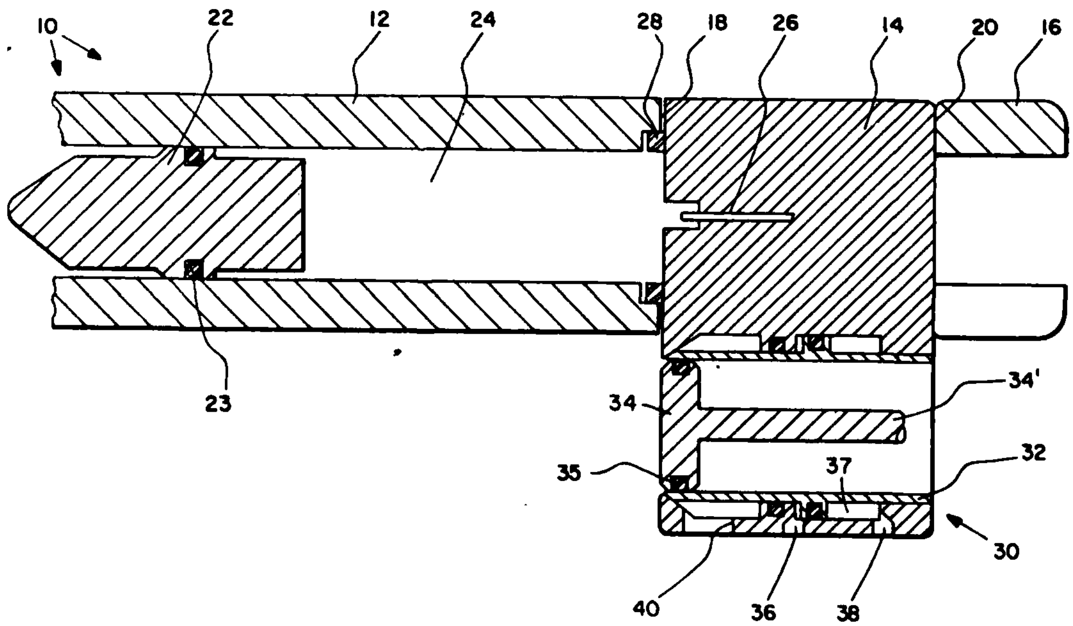
Primary Examiner—David H. Brown

Attorney, Agent, or Firm—R. S. Sciascia; Roy Miller; G. F. Baker

[57] **ABSTRACT**

The injector assembly for liquid propellant guns is slidably mounted for movement into or out of the firing chamber of the gun as a sliding breech block. The bolt is movable within the injector assembly in one portion and the firing device is chambered in the alternate portion of the block.

4 Claims, 3 Drawing Figures



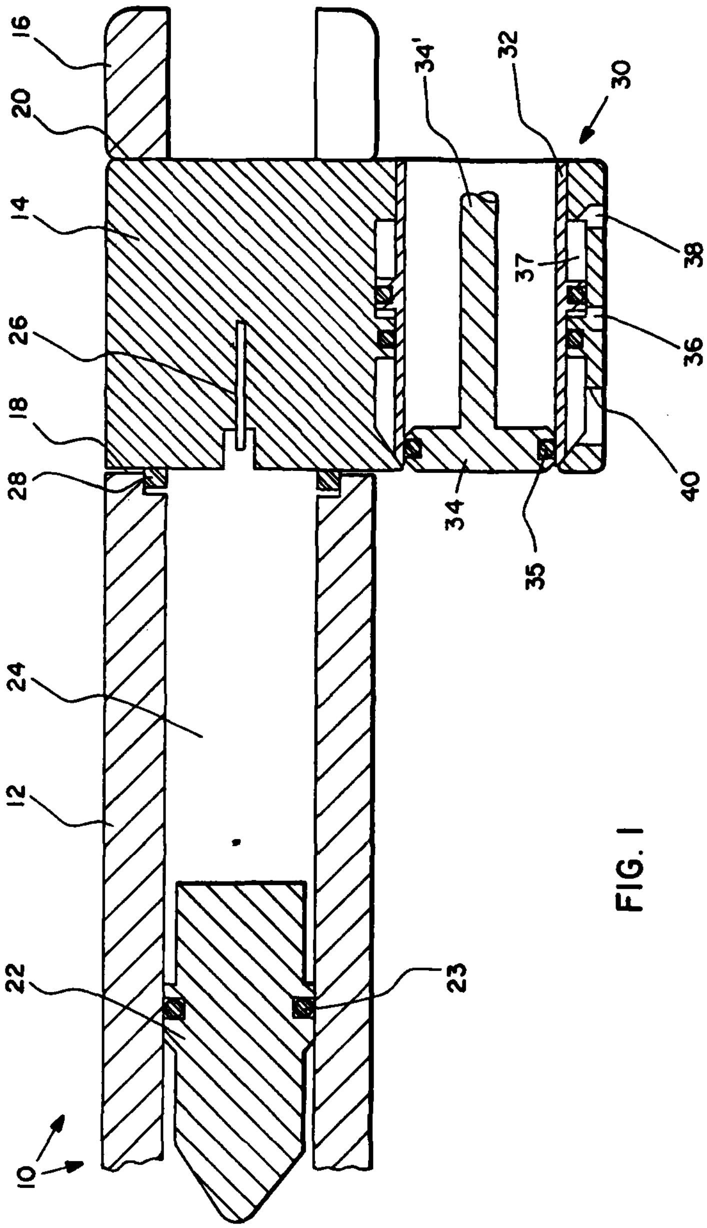


FIG. 1

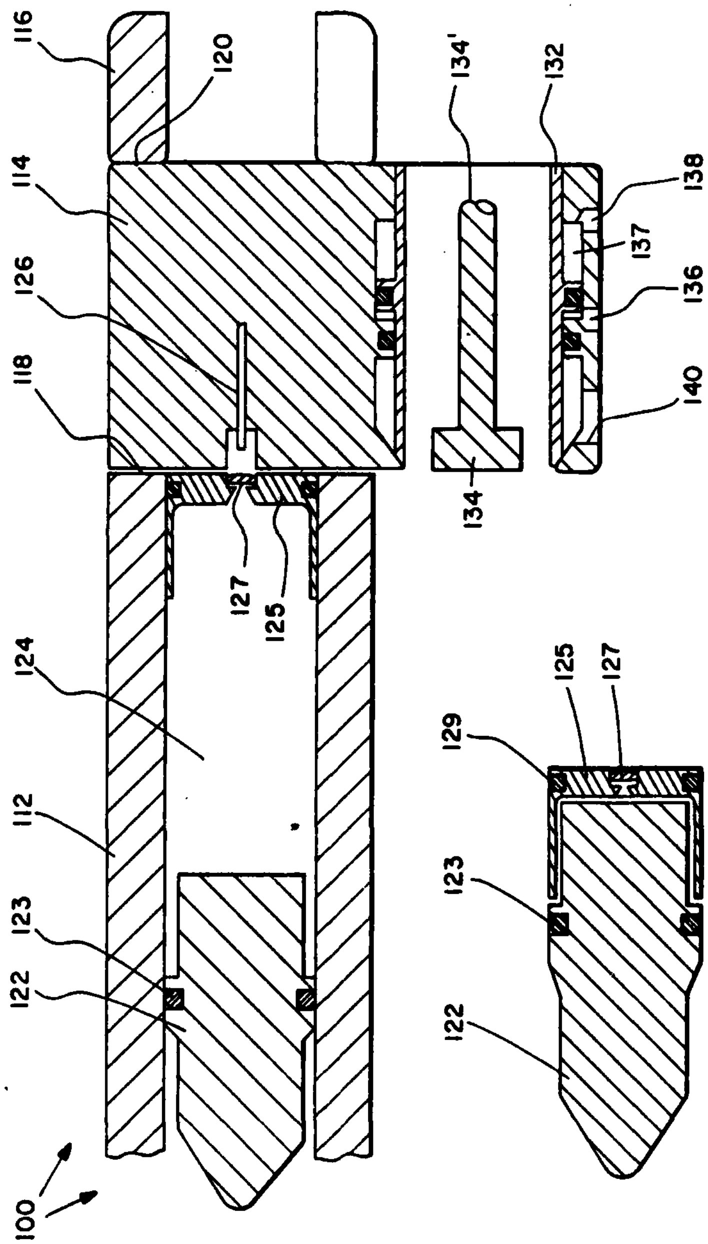

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FIG. 2

FIG. 3

LIQUID PROPELLANT GUN

BACKGROUND OF THE INVENTION

The present invention relates to liquid propellant guns and particularly to an injector assembly therefor. The invention has for an object thereof the prevention of back pressure on the injector mechanism.

Previous designs, for example, have subjected the injection mechanism to firing pressures. To survive firing, these components had to be small. This limited the propellant flow areas, slowing injection and rate of fire. Additionally, flow passages were left exposed, allowing ullage, unburned propellant, and structural weakening. Guns of this type have been known to fail by hot gas leakage into the injector mechanism often with resulting spontaneous disassembly.

The present invention is an improvement over the prior liquid propellant gun design disclosed in Assignee's prior application Ser. No. 612,817 filed Sept. 12, 1975 and identified as Navy Case No. 57678.

The design in assignee's prior application referenced above protects the injector mechanism by advancing the bolt to block the firing pressure. In other words, after injection, the bolt is moved forward translating the projectile, propellant charge, and bolt mechanism down bore until the end of the bolt is ahead of the injector. The bolt mechanism must then stop and lock the gun before firing. This protects the injector, but the bolt actuation and locking system is complicated and must be heavy enough to withstand firing pressures. Power requirements are high and the rate of fire is reduced as a consequence of the stop-start action.

SUMMARY OF THE INVENTION

According to the present invention the injector mechanism is protected from firing pressures by a device in the form of a sliding block. The injector mechanism and bolt are in one portion of the block and the firing device is in a second portion of the block. After injection, the block is moved to a position with the injector mechanism and bolt out of line with the barrel and with the firing device then in line with the barrel. Sliding the injector completely away from the high pressure area protects it and the propellant supply system from the high pressures and dangers of fuel or gas leakage. There are no passages, slots or holes exposed to propellant and breech pressures during firing. This eliminates pockets of trapped propellant as well as ullage and increases the strength of the high pressure area.

This arrangement also results in a short compact design well adapted to large caliber guns where a long bolt assembly would be unwieldy. Accordingly, the sliding breech block type injector module simplifies liquid propellant gun design by eliminating the complex bolt, bolt actuation, bolt jog and bolt lock of the prior mechanism resulting in faster firing rates made possible because the moving parts are smaller, lighter and moved through shorter distances.

BRIEF DESCRIPTION OF THE SEVERAL VIEWS OF THE DRAWINGS

FIG. 1 is a longitudinal cross sectional view of the breech area of a liquid propellant gun according to the invention designed to fire caseless ammunition;

FIG. 2 is a view similar to FIG. 1 of a modification for firing semi-cased projectiles; and

FIG. 3 is a longitudinal cross sectional view of a semi-cased projectile useable in the device of FIG. 2.

DESCRIPTION AND OPERATION

The breech area of a liquid propellant gun according to the invention is indicated generally by the numeral 10 in FIG. 1. The breech end of the barrel is indicated at 12, the breech block at 14 and the magazine side of the breech at 16. The block 14 slides in a slot 18 provided in the barrel-breech area the rear portion 20 of which slot provides the locking or reaction surface during firing.

The parts are shown in position ready for firing with the projectile 22 forward of the block 14 and presumably with the fuel chamber area 24 filled with liquid propellant fuel. The fuel is ignited by a spark igniter 26 which is shown chambered within the sliding block 14.

A circumferential breech seal 28 is recessed in the breech end of barrel 12 and is designed to react to the rising propellant pressures preventing the escape of the products of combustion.

The injector assembly 30 is located in the lower portion of block 14 and consists of a circumferential injection valve 32 coaxial with the projectile ram or bolt 34 and bolt actuator 34'. Movement of the injection valve 32 is accomplished by changing pressure in one side or the other of hydraulic control chamber 37 with hydraulic means through ports 36, 38 and the liquid propellant is supplied under pressure through the port 40 into the area 41 which is a part of the fuel chamber when block 14 is in the injection position.

With the parts in the position shown in FIG. 1, when it is desired to fire another projectile, the breech block 14 is shifted upwards until the axis of the injector valve 32 is in line with the bore. The projectile ram 34 is simultaneously withdrawn to pick up a new round from the magazine and then returns to ram the round into the breech block area. When the liquid seal 23 on the projectile 22 enters the barrel 12 the ram 34 is halted. The injection valve 32 is next opened by hydraulic signals through port 36 allowing an external pump to deliver a new charge of propellant. The new charge enters through a port 40 in the breech block and flows into the space between the projectile and ram. The liquid seal 35 on the ram 34 along with the seals 23 and 28 on the projectile and the breech end of the barrel respectively prevent leakage as the projectile is pumped into its firing position as shown in FIG. 1. After injection, the valve 32 is closed by hydraulic action and the ram moved forward until flush with the breech block as the breech block is shifted back to its position, as shown in FIG. 1, and the gun is ready to fire. The breech seal 28 is under pressure at this time and prevents leakage as the breech block shifts.

A modified liquid propellant gun is generally indicated in FIG. 2 by the numeral 100. The FIG. 2 device operates in all respects as the device of FIG. 1 with a few exceptions.

The projectile 22 which is used in the FIG. 2 devices comes equipped with a short case 125 as shown in FIG. 3. The case 125 is equipped with a standard pyrotechnic ignition system 127 and a sealing ring 129. The case 125 is assembled to projectile 122 with a fit light enough to insure relative separation during injection. After injection, the case, propellant charge, and projectile are rammed to the firing position shown in FIG. 2.

With this arrangement the breech end of the barrel and the ram need not be fitted with seals and the ram **134** may be modified to include a case extractor.

This arrangement simplified the gun design by providing a new high pressure breech seal and igniter for each slot. Additionally, the projectile base is enclosed and protected by the semi-case feature which advantageously protects the fuze, fins, rocket motor or guidance mechanisms in more complex projectiles.

What is claimed is:

1. In a gun,

a sliding breech block movable between a firing position and a loading position,

a firing device chambered in a first portion of said block,

valve means including a cylindrical valve slidably mounted in a second portion of said block and defining with said second block portion a fuel chamber and a hydraulic control chamber,

so that said valve means is removed from the breech area when the gun is in said firing position ready to be fired by said firing device.

2. The gun according to claim **1** further including:

a forward breech portion receiving a tubular barrel,

a rearward breech portion having a bore,

a bolt and bolt actuator mounted for sliding action in said bore and movable from a position wholly within said bore to a position within said second

block portion when said block is in said loading position.

3. The gun of claim **2** further including:

a first obturating seal in said barrel at the juncture of said forward breech portion and said block and a second obturating seal on the forward end of said bolt.

4. In a liquid propellant gun for firing semi-cased or uncased rounds, the combination comprising:

a gun barrel;

a breech;

a breech block slidably received in said breech and movable from a first position for firing and a second position for loading;

a firing device chambered in said block such as to be placed substantially concentric to and in communication with the bore of said barrel when said block is in said first position;

a cylindrical valve slidably mounted in said block such that said valve is placed concentric to and communicating with the bore of said barrel when said block is in said second position;

a bolt and bolt actuator associated with said block such that said bolt is slidably received within said valve so that;

when said block is in said first position, said firing device may be actuated for firing a projectile; and

when said block is in said second position, said bolt may be reciprocated to reload the gun.

* * * * *

United States Patent [19]

Holtrop

[11] **4,033,224**

[45] **July 5, 1977**

[54] **LIQUID PROPELLANT GUN**

[75] Inventor: **John W. Holtrop,** Ridgecrest, Calif.

[73] Assignee: **The United States of America as represented by the Secretary of the Navy,** Washington, D.C.

[22] Filed: **Sept. 16, 1976**

[21] Appl. No.: **723,880**

[52] **U.S. Cl.** .... **89/7;** 89/1 R

[51] **Int. Cl.²** **F41F 1/04**

[58] **Field of Search** .... 89/7, 1 R, 11

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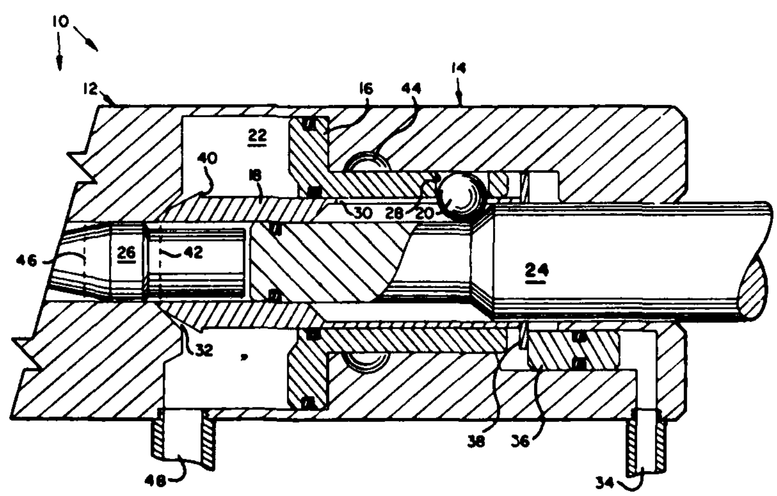
Primary Examiner—David H. Brown

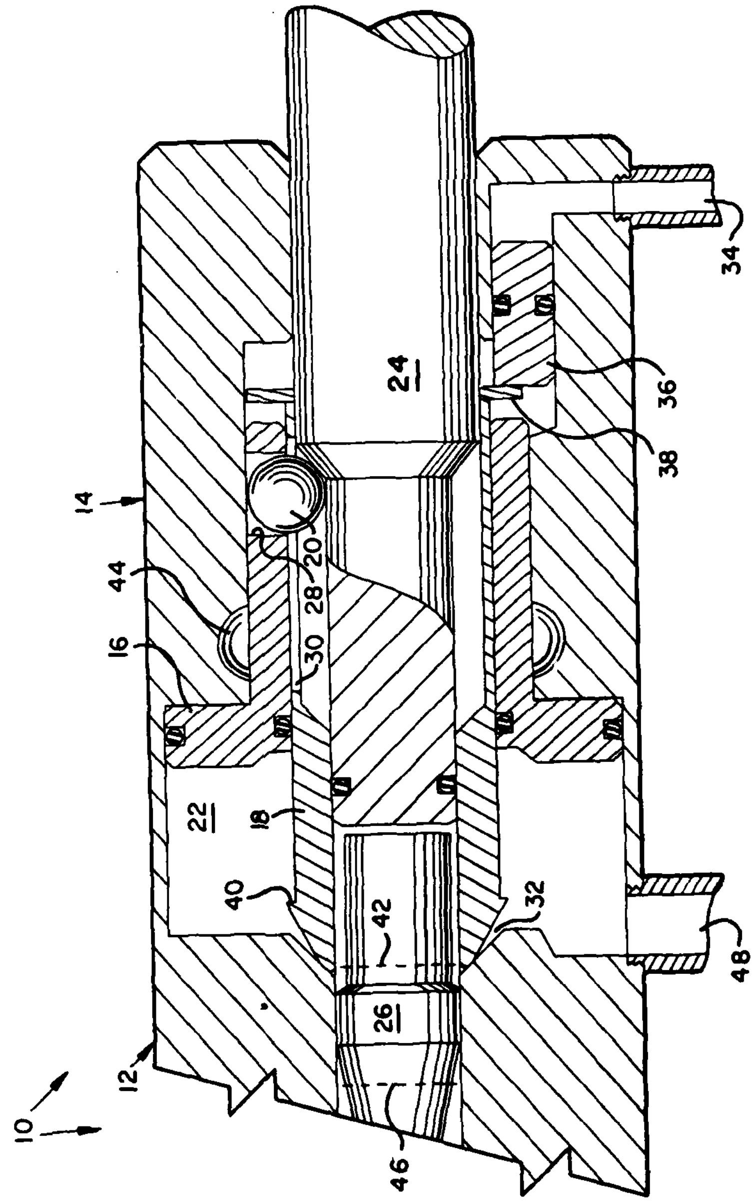
Attorney, Agent, or Firm—R. S. Sciascia; Roy Miller; Gerald F. Baker

[57] **ABSTRACT**

A liquid propellant gun featuring concentric propellant pump, valve and bolt. Forward movement of the bolt causes forward movement of the propellant pump by interconnection of ball detents. The valve is forced open by differential pressure and closed by abutment of pump surfaces. At this juncture the ball detent connection is relieved and the bolt continues forward to pressurize the propellant charge before firing.

10 Claims, 1 Drawing Figure

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LIQUID PROPELLANT GUN

BACKGROUND OF THE INVENTION

The present invention relates to liquid propellant guns, and more particularly, to a liquid propellant gun which includes a mechanism for synchronizing propellant injection with bolt-action for rapid fire.

Previous known designs have used switches to sense position and individual actuators to position the bolt, open the injection valve, pump the propellant, and close the valve. This is unacceptably slow, complex, and unreliable for rapid fire action. One prior art device has a drum cam containing separate cam paths cooperating with separate followers for actuating the bolt, valve, and propellant pump. This arrangement, however, results in a very complex, cumbersome and expensive system.

SUMMARY OF THE INVENTION

The present invention provides apparatus usable in liquid propellant guns such as those described in assignee's prior copending applications Ser. No. 612,817, filed Sept. 12, 1975 now U.S. Pat. No. 3,992,976 and Ser. No. 613,690 filed Sept. 15, 1975.

The present invention relates to a valve, pump, and bolt combination wherein the propellant pump and valve member are interconnected by a ball detent, for example, and wherein the valve is forced open by differential pressure and automatically closed, for example by abutment of pump surfaces. Forward movement of the bolt, in the preferred embodiment, causes forward movement of the propellant pump through the interconnection of a ball detent. After injection, the ball detent connection is relieved and the bolt continues forward to pressurize the propellant charge and seat the projectile before firing.

BRIEF DESCRIPTION OF THE SEVERAL VIEWS OF THE DRAWING

The sole FIGURE illustrated on the drawing is a partial longitudinal cross-sectional view taken in the breech area of a propellant gun according to the present invention.

DESCRIPTION AND OPERATION

The breech area of a liquid propellant gun according to the present invention is generally indicated at **10** on the drawing. The components shown include a barrel portion **12** and an integral receiver **14**. Contained within the barrel and receiver are a propellant pumping piston **16**, a propellant control valve **18**, and plurality of radially spaced synchronizing balls **20**.

The firing cycle begins with the pump piston **16** in the position shown. The chamber **22** in front of piston **16** is full of propellant and the valve **18** is closed. A projectile **26** has been loaded through an opening (not shown) in receiver **14** through the relieved portion of valve **18** while the bolt was in its rearmost position. This operation may be better understood by reference to Patent No. 3,992,976 referenced above. The bolt **24** began the cycle by pushing projectile **26** into the injection position shown. The bolt stopped when it engaged the synchronizer balls **20**, which are positioned in holes or bores **28** in the pump extension and confined in axial slots **30** provided in the body of valve **18**.

When bolt **24** and pump member **16**, locked together by the balls **20**, are moved forward they cause pressurization of the propellant in chamber **22**. A wedge shaped pumping area is formed between the tapered surface of the forward wall of chamber **22** and the tapered surface of the forward end of valve **18** is indicated at **32**. Propellant pressure acts on the wedge shaped valve "pumping area" **32**, causing the valve to open. The amount of pressure necessary to open the valve is determined by the contour of the "pumping area" and the closure force on the valve. The closure force is regulated by applying a constant hydraulic or pneumatic pressure through port **34** to a piston **36** which bears upons a flange **38** at the rear of the valve. When the valve opens, the bolt, ball and pump move forward, pumping propellant between the bolt and projectile.

Near the end of the injection, the pump piston **16** strikes a shoulder **40** on valve **18** forcing the valve closed. When the pump and valve are completely closed, chamber **22** is practically empty and the bolt nose is flush with the valve seat as indicated by dotted line **42**. In this position, the balls are in line with the circumferential groove **44** in the receiver. The balls are pushed into this groove as the bolt then moves forward into firing position indicated by dotted line **46**. This additional travel is designed to protect the injector valve and pump from breech pressure when the propellant is ignited.

After firing, the bolt is withdrawn allowing the synchronizer balls to drop out of their receiver groove **44** releasing the pump; fresh propellant is introduced through port **48** pushing the pump back to its original position and the assembly is in position to receive a new projectile. The cycle can then be repeated.

From the above it can be readily seen that this invention simplifies the synchronization problems inherent in liquid propellant guns. The multiple synchronizing balls control the position of the valve and pump under filling, pumping, and firing conditions, and maintain the required gun kinematics. The bolt is the only component which requires actuation from an external source.

The pump, valve, and synchronization mechanism may be contained within a single replaceable module allowing low-cost fabrication and easy maintenance. Further, since the synchronizer balls hold the valve and pump locked closed and empty whenever the bolt is in the firing position, the quantity of propellant present and thus the danger of damage is minimized in case of a casualty.

Although only one embodiment of the invention has been described and illustrated, it should be mentioned that pumping forces on the bolts may be relieved by slight modifications of the system. One suggested modification comprises a hydraulic pump actuator built into the receiver which may be actuated by a signal from the bolt to help move the propellant pump. This arrangement removes some of the load from the synchronizer balls during the injection cycle. Also, the closure pressure through port **34**, may be relieved upon a signal from the bolt movement, venting the pressure at that point, thus allowing the valve to be popped open substantially without resistance. This arrangement reduces pumping loads both on the bolt and the synchronizer balls.

Alternatively, the balls can be arranged to strike the end of the valve slot **30** to close the valve, thus eliminating the need for shoulder **40** on valve body **18**. Another option for closing the valve would be to slow the

bolt toward the end of the injection cycle and allow the closure piston 36, to close the valve. Further, a combination of the last two alternatives has been suggested.

What is claimed is:

1. In a liquid gun having a barrel, a receiver, a chamber, a bolt slidably mounted in said receiver and chamber for reciprocating motion along the axis of said barrel, and means for injection of fuel for firing a round from said barrel, the improvement comprising:

valve means in said receiver cooperating with said bolt for controlling access of fuel to said chamber;

pump means in said receiver coaxial with said bolt and cooperating with said valve means and said bolt to pressurize fuel in said chamber.

interconnecting means linking said valve means and said pump means and responsive to action of said bolt to effect injection of fuel from said chamber to a position between the bolt and the round.

2. The liquid propellant gun of claim 1 wherein said interconnecting means comprises a sphere confined in a closely fitting opening in said pump means and riding in an elongated slot in said valve means.

3. The liquid propellant gun of claim 1 wherein said interconnecting means comprises at least one detent member slidably mounted in a bore in said pump means and including a portion thereof riding in a slot in a portion of said valve means.

4. The liquid propellant gun of claim 1 wherein said valve means is biased to a closed position by a constant fluid pressure.

5. The liquid propellant gun of claim 4 wherein said interconnecting means comprises at least one detent member slidably mounted in a bore in said pump means and including a portion thereof riding in a slot in a portion of said valve means.

6. The liquid propellant gun of claim 5 and each said detent member being a metal sphere.

7. The liquid propellant gun of claim 1 further including:

a first tapered surface forming a portion of the forward wall of said chamber in line with the forward end of said valve means; and

a second tapered surface on the forward end of said valve means;

said tapered surfaces being at slightly differing angles to the longitudinal axis of the barrel so as to form a wedge shaped pumping area;

whereby, when propellant is forced into said chamber, pressure building up in said pumping area will cause opening of said valve means.

8. The liquid propellant gun of claim 7 wherein said valve means is biased to a closed position by a constant fluid pressure.

9. The liquid propellant gun of claim 7 wherein said interconnecting means comprises at least one detent member slidably mounted in a bore in said pump means and including a portion thereof riding in a slot in a portion of said valve means.

10. The liquid propellant gun of claim 9 and each said detent member being a metal sphere.

* * * * *

United States Patent [19]

Petersen et al.

[11] **4,091,711**

[45] **May 30, 1978**

[54] **ROTARY BOLT LIQUID PROPELLANT GUN**

[75] Inventors: **Gary L. Petersen; John W. Holtrop,** both of Ridgecrest, Calif.

[73] Assignee: **The United States of America as represented by the Secretary of the Navy,** Washington, D.C.

[21] Appl. No.: **800,751**

[22] Filed: **May 26, 1977**

[51] Int. Cl.² **F41F 1/04**

[52] U.S. Cl. .... **89/7**; 89/13 A; 89/17

[58] **Field of Search** .... 89/7, 13 A, 17, 33 MC, 89/13 R; 42/9, 39.5

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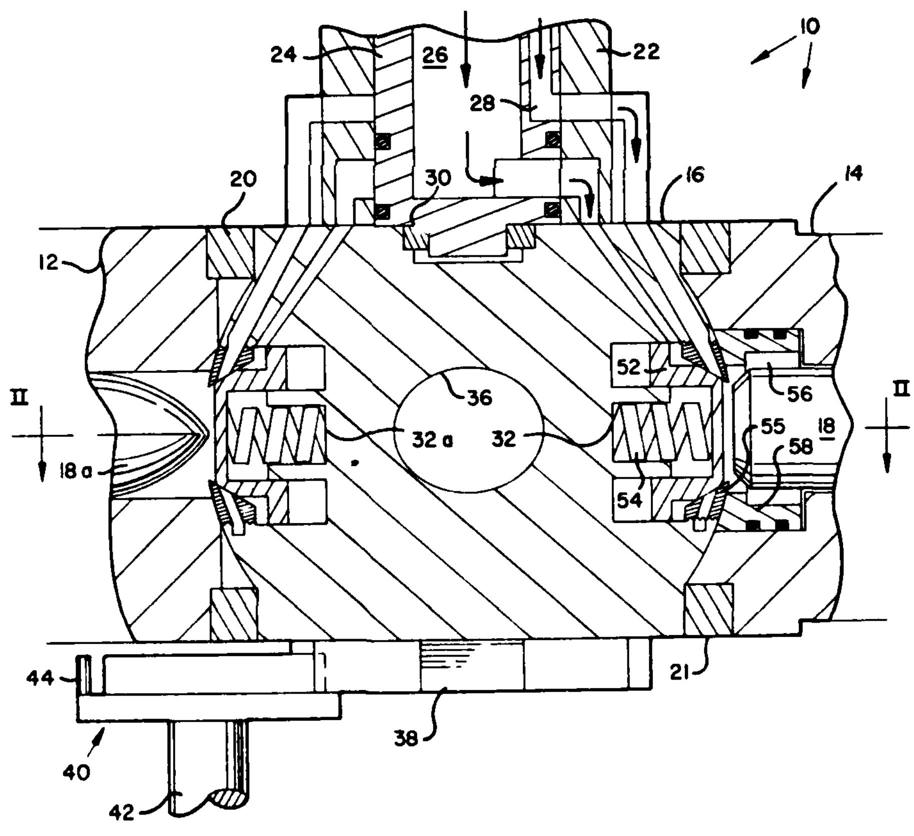
Primary Examiner—David H. Brown

Attorney, Agent, or Firm—R. S. Sciascia; Roy Miller; W. Thom Skeer

[57] **ABSTRACT**

A liquid propellant gun loading, propellant injection and firing mechanism characterized by a rotating breech block having a generally spherical contour. The breech block is intermittently rotated to and locked in sequential loading, fuel injection and firing positions.

6 Claims, 5 Drawing Figures



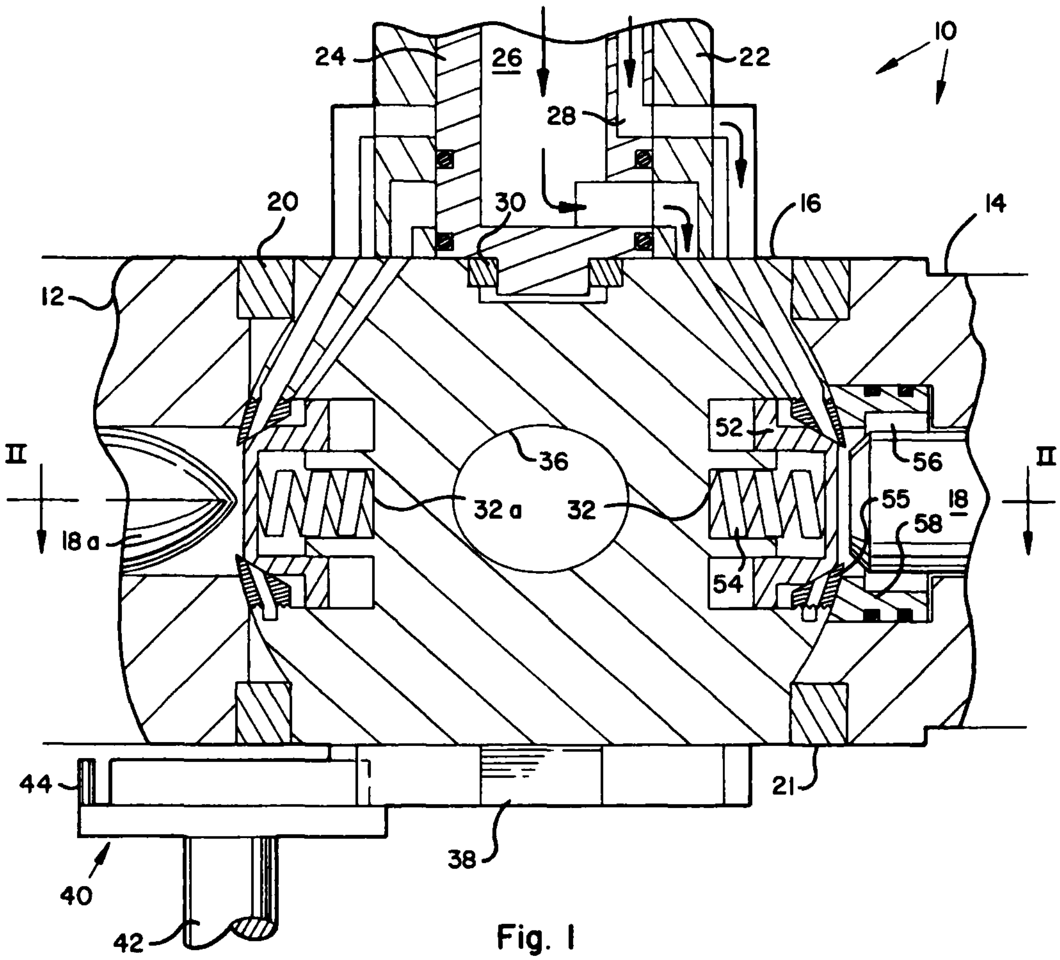

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Fig. 1

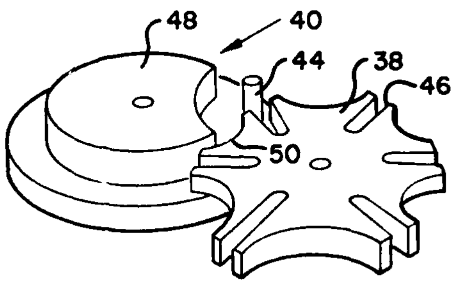
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Fig. 2

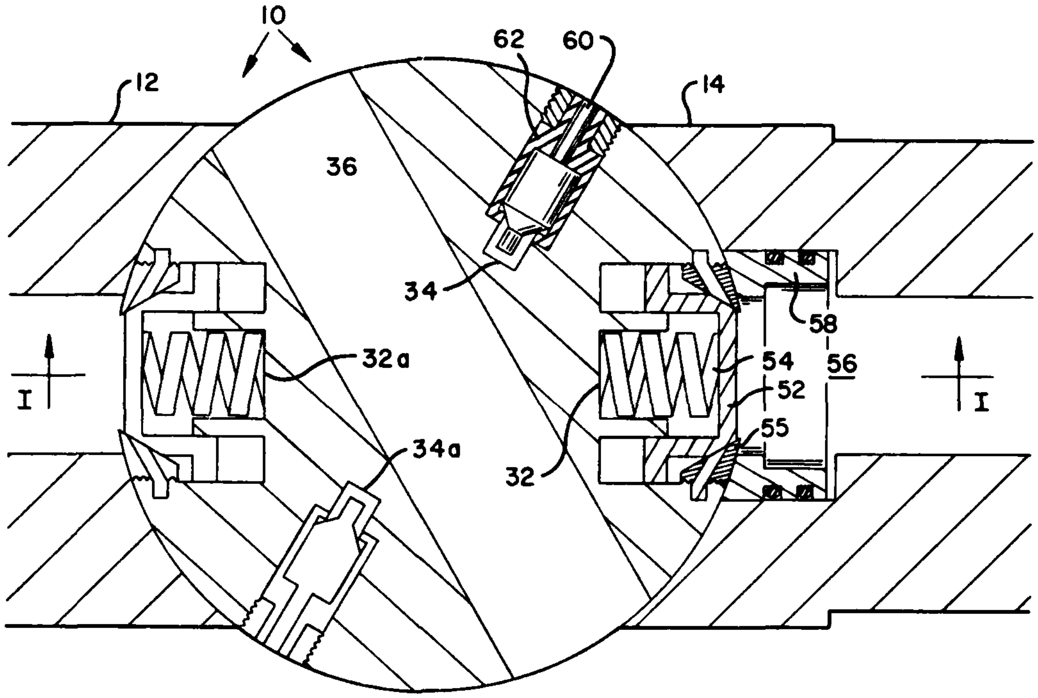

Fig. 3

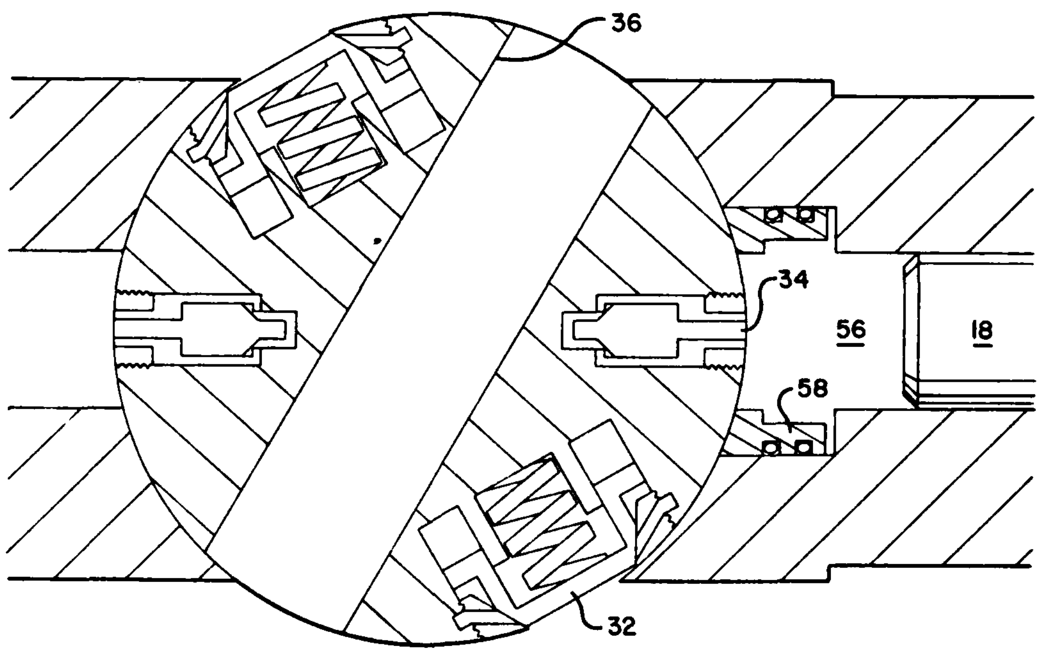

Fig. 4

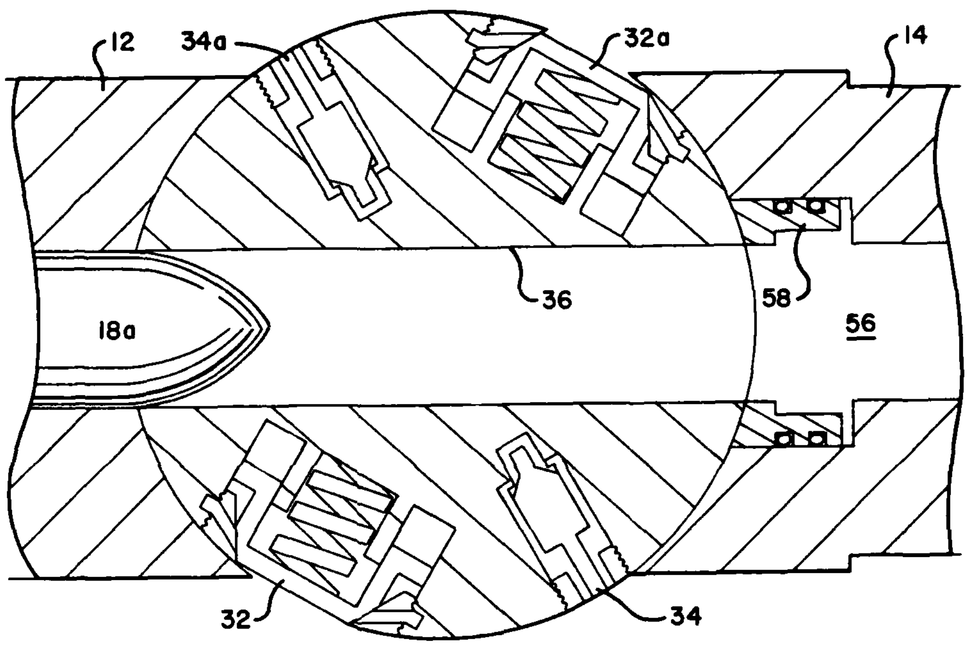

Fig. 5

ROTARY BOLT LIQUID PROPELLANT GUN

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates to liquid propellant guns and particularly to a novel loading, propellant injection and firing mechanism.

2. Description of the Prior Art.

Generally, liquid propellant guns all contain a mechanism for injecting the propellant. Current designs use injection valves which cannot be exposed to high firing pressures and the injection mechanism is therefore protected from the firing pressures by using a sliding bolt. After injection, for example, the bolt moves forward in the breech, pushing the propellant column and projectile before it down the bore, until a bolt seal is ahead of the injector area. An example of this type of gun is disclosed in assignee's prior application, Ser. No. 612,817 filed Sept. 12, 1975, and now U.S. Pat. No. 3,992,976 issued Nov. 23, 1976. Although this prior design operates satisfactorily, the bolt actuating and locking system is complicated, has high power requirements and slows the rate of fire because of the start and stop action.

SUMMARY OF THE INVENTION

According to the present invention, the propellant injection valve mechanism and the firing device are arranged in space relationship within a rotary breech block in the same general plane with a central bore, orthogonal to the axis of rotation of the block. The breech block also includes an axial liquid propellant transfer arrangement designed to supply a liquid fuel and an oxidizer to the injection valve mechanism. The rotary breech block herein disclosed completely protects the injection system by moving the valve mechanism out of register with the firing chamber before ignition. The rotary breech block mechanism is designed to be moved intermittently through at least 3 sequential positions for loading, injection and firing respectively.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a longitudinal cross sectional view in the breech area of a liquid propellant gun according to the present invention;

FIG. 3 is a cross sectional view of the FIG. 1 mechanism taken along line II—II;

FIG. 2 is a schematic plan view of the drive mechanism of FIG. 1;

FIG. 4 is a view similar to FIG. 2 showing the rotary bolt in the firing position; and

FIG. 5 is a view similar to FIG. 2 with the bolt in the loading position.

DESCRIPTION OF THE PREFERRED EMBODIMENT

A rotary bolt liquid propellant gun breech area incorporating the present invention is generally indicated at 10 in FIG. 1. The loading end of the breech area is generally indicated at 12; the barrel is generally indicated at 14; and the rotary breech block is generally indicated at 16. A round 18 is shown in the barrel and a round 18a is shown in the load area.

The rotary breech block 16 is rotatably mounted in the breech area by means of two bearings 20, 21 and receives fuel and oxidizer through a rotary joint between a transfer housing sleeve 22 fixed on the block and a stationary transfer or feed tube 24. In the embodiment illustrated, the feed tube 24 is divided into two separate channels 26, 28 which supply an oxidizer and fuel respectively. The breech block end of delivery tube 24 rests in a bearing 30 fixed in the face of block 16.

Between bearings 20 and 21 the outer surface of breech block 16 is spherical in contour and closely fits within mating concave spherical contours in the loading end 12 and barrel end respectively of breech area 10. In the embodiment shown, block 16 contains two identical poppet valves 32, 32a; two identical firing devices 34, 34a (see FIG. 3) and a central bore 36.

The breech block 16 is designed to be driven intermittently and, for this purpose, carries a six lobed geneva wheel 38 integral with the face of breech block 16 opposite feed tube 24, and coaxial thereto. The geneva wheel 38 is driven by a geneva wheel driver 40 which, inturn, may be driven by a constant speed motor (not shown) through shaft 42. FIG. 2 illustrates how a pin 44 on geneva wheel driver 40 cooperates with slots 46 on geneva wheel 38 to intermittently drive wheel 38. Between drive periods, a locking surface or cam 48 cooperates with one of the surfaces 50 between slots on geneva wheel 38 to prevent any movement of wheel 38 during that time.

FIGS. 1 and 3 illustrate the device at the beginning of an injection cycle. Valve 32 is in position to receive fuel and oxidizer through ports 26, 28 and when pressure is applied by the fuel and oxidizer the valve body 52 will be pushed back by this pressure against the bias of spring 54 and chamber 56 will be filled with liquid, pushing the round 18 forward in the barrel as shown in FIG. 4. Pressure will also act upon chamber seal 58 to press against the spherical surface of breech block 16.

After injection of the measured amount of propellant has been accomplished, the breech block is next rotated to the position shown in FIG. 4 with the igniter 34 in position to ignite the fuel in chamber 56, forcing the round 18 out of the barrel. Following this step, the next increment of rotation of block 6 places the parts in the position shown in FIG. 5, allowing the round 18a to be advanced through the bore 36 into chamber 56. This may be accomplished mechanically, for example, by a ram (not shown) or by pneumatic pressure.

The igniter shown in the above embodiment is shown as an electrical spark type but it may, of course, be any type of igniter suitable for the purpose. Similarly, the drive mechanism is shown as a geneva type drive but any intermittent drive which will lock at each position would serve as well. The same rotary breech block concept can be adapted to small or large bore guns.

This invention completely protects the injector mechanism from gun gas pressures at ignition by moving the valve mechanism out of the chamber area before firing. The sealing surfaces consist of easily machined spherical contours and no bolt lock mechanism is required.

For a firing speed of about a thousand rounds per minute, the shaft 42 of the geneva wheel driver rotates at a constant 3,000 revolutions per minute. At this speed, the geneva mechanism will cause the breech block to dwell at each station for about 13 milliseconds. The six lobed geneva wheel and the duplicate valves and igniters are used to reduce breech block acceleration and drive motor power requirements. For slower rates of fire, a three or four station block could be used with a three or four lobed geneva wheel, for example, to

further reduce size and increase dwell time at each position.

What is claimed is:

1. A liquid propellant gun breech loading, injection and firing mechanism comprising;

a liquid propellant gun body including a rearward loading portion, a forward barrel portion and a rotatable breech block intermediate said rearward and forward portion;

said gun body having oppositely facing contoured portions between said rearward and forward portion;

said rotatable breech block mechanism comprising contoured surfaces complimentary to said contoured surfaces on said rearward loading and forward barrel portions so that said breech block may be closely confined between said contoured surfaces for rotary motion around an axis perpendicular to the axis of said barrel portion;

said breech block further comprising a fuel transfer housing having a cylindrical inner bore coaxial with said rotational axis for receiving therein a fuel transfer tube;

said breech block further comprising a central bore, at least one injection valve mechanism and at least one firing device each having an axis of symmetry within a plane passing through the barrel axis and perpendicular to the axis of said fuel transfer housing; and

means for incrementally moving said breech block to serially position said bore, said injection valve mechanism and said firing mechanism respectively in line and register with said barrel.

2. The apparatus of claim 1 wherein said breech block contains diametrically opposed injector valve mechanisms and two diametrically opposed igniter mechanisms and wherein the axis of symmetry of said injector valve mechanisms and said igniter devices are spaced thirty degrees from the axis of symmetry of said bore and from each other.

3. The apparatus of claim 1 wherein said contoured surfaces of said breech block are substantially spherical.

4. The apparatus of claim 1 wherein said means for incrementally moving said breech block is a six lobed Geneva-type mechanism locking said breech block in six respective positions.

5. The apparatus of claim 4 wherein said breech block contains two diametrically opposed injector valve mechanisms and two diametrically opposed igniter mechanisms and wherein the axis of symmetry of said injector valve mechanisms and said igniter devices are space thirty degrees from the axis of symmetry of said bore and from each other.

6. The apparatus of claim 5 wherein said contoured surfaces of said breech block are substantially spherical.

* * * * *

United States Patent [19]

Ayler et al.

[11] 4,160,405

[45] Jul. 10, 1979

[54] LIQUID PROPELLANT GUN, POSITIVE DISPLACEMENT SINGLE VALVE

[75] Inventors: Steven E. Ayler, China Lake; John W. Holtrop, Ridgecrest, both of Calif.

[73] Assignee: The United States of America as represented by the Secretary of the Navy, Washington, D.C.

[21] Appl. No.: 879,555

[22] Filed: Feb. 21, 1978

[51] Int. Cl.² F41F 1/04

[52] U.S. Cl. 89/7; 89/11

[58] Field of Search 89/7, 11

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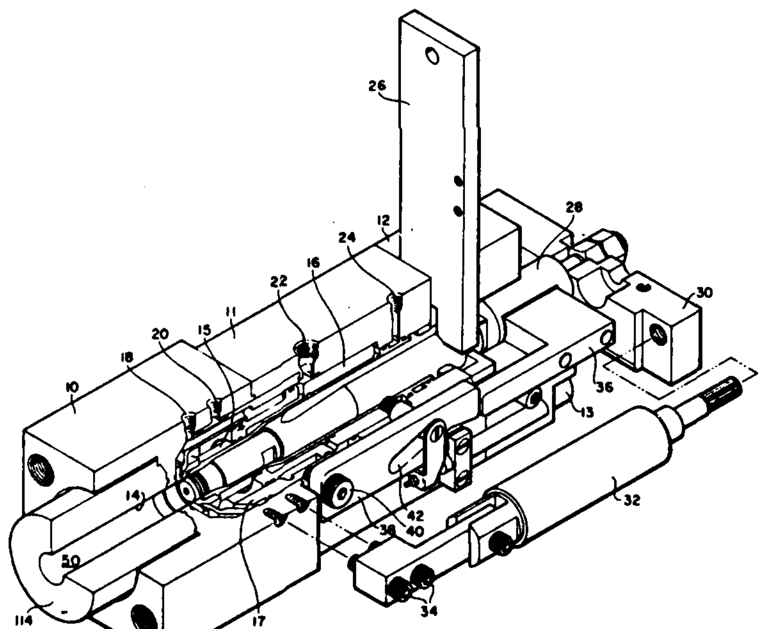
Primary Examiner—David H. Brown
Attorney, Agent, or Firm—R. S. Sciascia; W. Thom Skeer

[57] ABSTRACT

An improved bi-propellant injection system for a liquid propellant gun including a valve which is positively opened at the start of the injection of the fuel and oxidizer into the gun chamber and held at a predetermined displacement to provide a constant size propellant orifice throughout the fu~l and oxidizer injection cycle.

10 Claims, 2 Drawing Figures



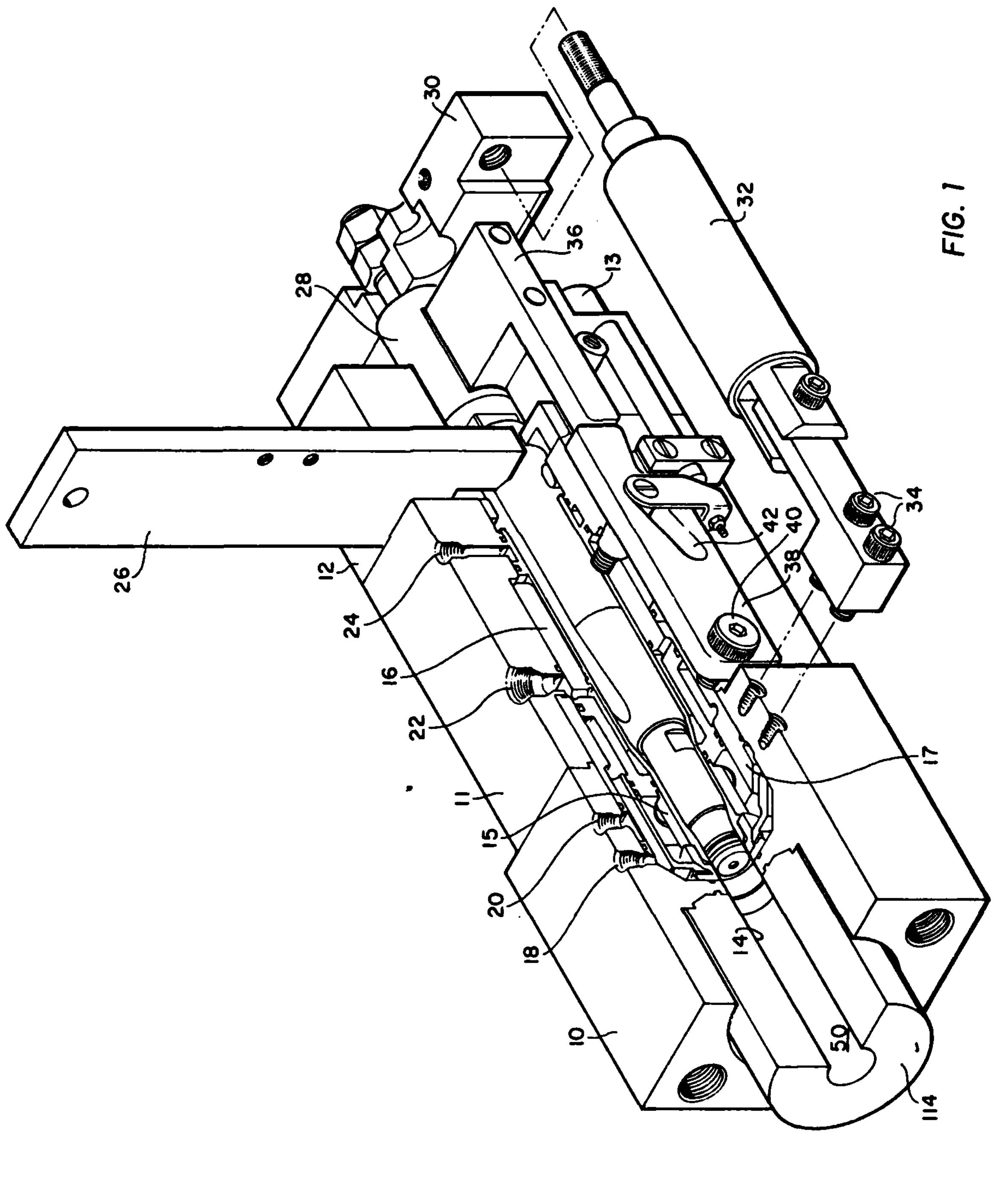


FIG. 1

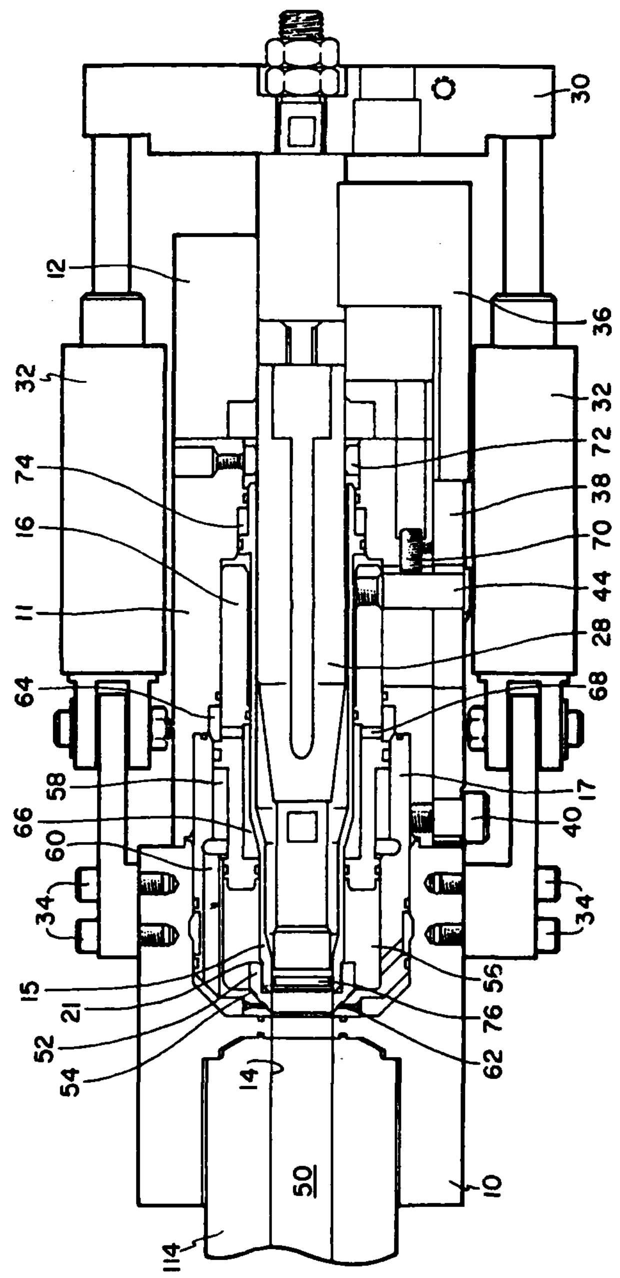

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FIG. 2

LIQUID PROPELLENT GUN, POSITIVE DISPLACEMENT SINGLE VALVE

BACKGROUND OF THE INVENTION

1. Field of the Invention

The strong influence of propellant mixing on liquid propellant gun interior ballistics has been recognized and studied. A measuring technique to determine the degree of mixing has been developed and indicates that gun performance can be varied from misfires through normal burns to detonation simply by varying the severity of the injection. This knowledge has underscored the need for better control of the injection process in the liquid propellant gun technology.

2. Description of the Prior Art

In present bi-propellant liquid propellant guns, the displacement of the valves during injection of the fuel and oxidizer into the chamber of the gun barrel is determined by the force equilibrium between propellant and holding pressures. This method leaves the valves vulnerable to influence from O-ring friction, bolt nose side loads, trapped air, and oscillatory propellant and holding pressures. The valves do not repeat the same displacement-time history from injection-to-injection, thereby resulting in non-reproducible propellant mixing. Control of all variables affecting internal ballistics is important if consistant results are to be obtained.

SUMMARY OF THE INVENTION

The invention comprises an improved bi-propellant injection system for liquid propellant guns wherein the displacement of the valves is accomplished through a positive actuation system. The liquid propellant gun comprises a receiver block having a central cavity therein which houses a valve having a forward nose portion which seats against a manifold in fluid communication with the chamber of a gun barrel. The barrel is affixed to the receiver block. Surrounding the valve is an injector piston which is adapted to move axially with respect to the valve and the receiver block. Oxidizer and fuel receiving receptacles are provided within the receiver block and are in communication with the injector piston.

A positive stop is provided rearwardly of the injector piston in the receiver block as well as a positive stop in the receiver block to limit rearward travel of the valve upon opening. Injection of the fuel and oxidizer into the gun barrel chamber is attained when a source of hydraulic fluid under high pressure acts on the injector piston relative to the valve thereby forcing the injector piston forwardly toward the gun chamber and the valve rearwardly against the stop in the receiver block.

In the improved system of the invention the valve is positively opened at the start of the injection cycle and held at a predetermined displacement. This produces a constant size propellant orifice throughout most of the injection cycle.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is an isometric view, partly cut away, of a liquid propellant gun;

FIG. 2 is a cross-section along the centerline of the embodiment of FIG. 1.

DESCRIPTION OF THE PREFERRED EMBODIMENT

With respect to FIG. 1, in the present configuration the injector is housed within two large blocks **10** and **11** formed of suitable material such as stainless steel. A receiver block **12** attaches to the rear of block **11** and four long stringer bolts, one of which is shown at **13**, hold blocks **10**, **11** and **13** together.

A gun barrel **114** having a chamber **14** is internally mounted at the forward end of block **10**. Rearwardly of chamber **14** is a long slender valve **15**. Surrounding valve **15** is an injector piston **16** which is adapted for axial movement relative to the valve **15** in the blocks in which it is housed.

A propellant manifold **17** is also mounted within the cavity in blocks **10** and **11** and surrounds the injector piston **16**.

Fuel is introduced to the propellant manifold **17** through inlet **18**. Oxidizer is introduced to the manifold **17** through inlet **20**. Both inlets **18** and **20** are located in block **10**.

A source of high pressure hydraulic fluid is introduced through inlet **22** while a similar source of holding pressure fluid is introduced through inlet **24** both of which are shown in block **11**.

Rearwardly of block **11** is a guillotine bolt lock **26** which acts to lock a bolt assembly **28** in the forward position prior to firing. Bolt **28** is mounted for reciprocal movement toward and away from the chamber **14** and the movement is accomplished by means of a yoke **30** affixed to the rear of bolt **28** which is coupled to air cylinders, one of which is shown at **32**. Air cylinders **32** are mounted to block **10** by means of screws **34**.

A cam follower **36** is also part of bolt assembly **28** and is adapted to bear on and cooperate with a cam **38** which pivots about a shoulder screw **40**. Cam **38** is caused to rotate about shoulder screw **40** through the interaction of a cam slot **42** and a jog release pin **44**.

FIG. 2 is a cross-section through the assembly showing the injector system in greater detail. Chamber **14** is shown as having a bore **50**. Rearwardly of the chamber **14** and bore **50** is a foreward nose portion **52** on valve **15** which cooperates with a portion **54** on the propellant manifold **17**. The rear portion at the nose **52** forms a stop **21**.

Propellant manifold **17** is shaped to provide an oxidizer receiving recess **56** and a fuel receiving recess **58** therein. Axial and radial holes **60** and **62**, respectively, in the propellant manifold **17** allow introduction of the fuel to the chamber of the gun prior to firing.

Injector piston **16** is shaped to provide hydraulic cavities **64** and **66** between the piston **16** and block **11** and piston **16** and valve **15** respectively. Radial passageways **68** allow fluid communication between the cavities **64** and **66**.

Rearward movement of jog release pin **44**, and injector piston **16**, is limited by a charge/mass adjustment screw **70** while rearward travel of valve **15** is limited by an adjustable valve stop **72** comprising a threaded ring.

Operation of the system will now be described with respect to FIGS. 1 and 2. During the time that the propellant and oxidizer are being loaded into cavities **58** and **56** respectively, the valve **15** is maintained in a closed position by means of holding pressure in a cavity **74**. Loading of the fuel and oxidizer forces the injector piston **16** rearwardly until jog release pin **44**, contacts the charge/mass adjustment screw **70**. This measures

the charge of propellant to be injected. Pressure in cavity **74** holds the valve **15** closed during the filling process. During this time, the bolt assembly **28** is ordinarily moved rearwardly out of the interior of the valve **15** by means of the air cylinders **32**.

Once the fuel and oxidizer have been introduced into their respective cavities, a projectile and the bolt assembly **28** are inserted into the interior of valve **15** and pushed forward until the cam follower **36** contacts the rear surface of cam **38**. At this time, the air cylinders **32** exert a constant forward load on the bolt assembly **28** and another air cylinder (not shown) exerts a constant downward load on the bolt through the guillotine bolt lock **26**.

Injection of the fuel and oxidizer into chamber **14** begins as high actuation pressure is introduced into cavities **64** and **66**. Simultaneously therewith, valve **15** is forced rearwardly against the adjustable valve stop **72** and the injector piston **16** is forced forwardly thereby pumping propellant into the gun bore **50**. Oxidizer flows from chamber **56** directly over the valve nose **52** and fuel flows from chamber **58** through the axial holes **60** and then through the radial holes **62** into the bore **50**. The projectile is pumped forwardly into the chamber **14** by the propellant pressure.

Near the end of the injection of the fuel and oxidizer into the chamber, the front of the injector piston **16** contacts stop **21** on the valve nose **52** and forces the valve closed. Simultaneously, the cam **38**, after rotating upwardly due to the forward motion of the jog pin **44**, releases the cam follower **36**. That is, cam **38** rotates upwardly around shoulder screw **40** allowing cam follower **36** to pass thereunder.

The entire bolt assembly **28** jogs forward until the cam follower **36** contacts the receiver block **12**. This jog travel pushes the projectile, propellant column, and bolt nose breech pressure seal **76** completely into the chamber **14**. At this time, the guillotine bolt lock **26** drops down into an opening in bolt assembly thereby locking the bolt into place. Then, an electric spark produced in the face of the bolt nose ignites the propellant causing discharge of the projectile from the gun barrel.

The improvement in the present injector over previous designs is the ability to repeatably control propellant mixing. This is accomplished by having the valve positively opened at the start of injection and held at a predetermined displacement to provide a constant size propellant orifice throughout most of the injection cycle. Also, the radial fuel passages in the propellant manifold fix the size of the fuel orifice at the point where fuel meets oxidizer which is flowing over the face of the valve. The single valve concept eliminates the possibility of two simultaneously operating valves affecting each other and thereby varying the mix.

Other unique features are that the hydraulic pressure which actuates the injector piston also forces the valve open. In addition, a replaceable manifold surrounding the injector piston directs fuel and oxidizer to the injection port. Also, a synchronization mechanism consisting of the cam **38**, cam follower **36** and jog pin **44** release the bolt assembly **28** at the end of the injection thereby allowing the bolt to jog forward into the fire position.

An alternate configuration could be to pump fuel to the injection port through axial holes in the single valve rather than through radial holes in the propellant manifold. The design could also be modified to an old style twin valve configuration with one valve for fuel and one valve for oxidizer while retaining the positive valve opening feature.

What is claimed is:

1. An injection system for a liquid propellant gun comprising:
   - a chamber for receiving propellant and oxidizer liquids;
   - a receiver connected to said chamber;
   - a manifold within said receiver and having passages in fluid communication with said chamber;
   - a valve mounted within said manifold for selective movement between two positions, one position providing fluid communication between said passages in said manifold and said chamber and one position in fluid sealing relation between said passages in said manifold and said chamber;
   - a piston slidably mounted within said valve and configured relative to said valve to form two recesses therebetween; and
   - actuation means operatively connected to said piston and said manifold for selectively moving said manifold means to said fluid communication position and to move said piston so as to change the dimensions of said two recesses when said valve in said fluid communication with said chamber, whereby the contents of said recesses may be transferred to said chamber.

2. An injection system according to claim **1** wherein the actuation means is hydraulically coupled to said piston.

3. An injection system according to claim **1** further comprising a bolt mounted for reciprocative movement within said receiver.

4. An injection system according to claim **1** including;
   - oxidizer conduit means in said receiver and in fluid communication with one of said two recesses formed by the relative configuration of said valve and piston for transferring oxidizer thereto; and
   - propellant conduit means in said receiver and in fluid communication with second of said two recesses formed by the relative configuration of said valve and piston for transferring propellant thereto.

5. An injection system according to claim **4** wherein the fluid communication between said oxidizer conduit means, said propellant conduit means and said two recesses is via said manifold.

6. An injection system according to claim **1** further including limit means carried by said receiver for contracting said piston to restrict movement thereof.

7. An injection system according to claim **6** wherein introduction of oxidizer and propellant within said recesses forces said piston against said limit means.

8. An injection system according to claim **7** further including:
   - oxidizer conduit means in said receiver and in fluid communication with one of said two recesses formed by the relative configuration of said valve and said piston via apertures in said manifold for transferring oxidant therethrough; and
   - propellant conduit means in said receiver and in fluid communication with the other of said two recesses formed by the relative configuration of said valve and said piston via apertures in said manifold for transferring propellant therethrough.

9. An improved bi-propellant injection system for a liquid propellant gun wherein the improvement comprises an arrangement for repeatably controlling propellant mixing, said arrangement including;

a receiver block having a cavity therein;

a gun barrel mounted on said receiver block and having a propellant receiving chamber at one end thereof;

manifold means in said receiver adjacent said chamber and in fluid communication therewith;

valve means mounted rearwardly of said chamber and coaxial therewith and having a forward nose portion adapted to provide a fluid tight seal with respect to said manifold piston means in the cavity in said receiving block and coaxially mounted with respect to said valve means and configured for relative axial movement with respect thereto;

said cavity being formed with fuel and oxidizer receiving portions;

said receiving and oxidizer portions being in fluid communication with said valve means and said piston injector means;

axial travel limiting means mounted in said receiver block rearwardly of said piston injector means and adapted to limit the rearward movement of said piston means;

injection passageways for conveying fuel and oxidizer into said fuel and oxidizer receiving portions;

said fuel and oxidizer forcing said piston means rearwardly against said travel limiting means to thereby precisely control the amount of fuel and oxidizer in said receiving portions; and

positive actuating means acting on said piston means and said valve means to cause said valve means to move rearwardly with respect to said piston means to thereby provide a predetermined orifice opening with respect to said manifold.

10. An improved bi-propellant injection system according to claim 9 wherein said positive actuating means includes a hydraulic fluid coupling.

* * * * *

United States Patent [19]

Peterson et al.

[11] **4,170,922**

[45] **Oct. 16, 1979**

[54] **IGNITOR**

[75] Inventors: **Gary L. Peterson; Larry L. Liedtke,** both of Ridgecrest, Calif.

[73] Assignee: **The United States of America as represented by the Secretary of the Navy,** Washington, D.C.

[21] Appl. No.: **833,852**

[22] Filed: **Sep. 16, 1977**

[51] **Int. Cl.**[2] **F41F 1/04;** H01T 13/20

[52] **U.S. Cl.** 89/7; 313/138; 313/139; 313/143

[58] **Field of Search** .... 102/203, 28 R; 89/7; 313/138, 139, 143

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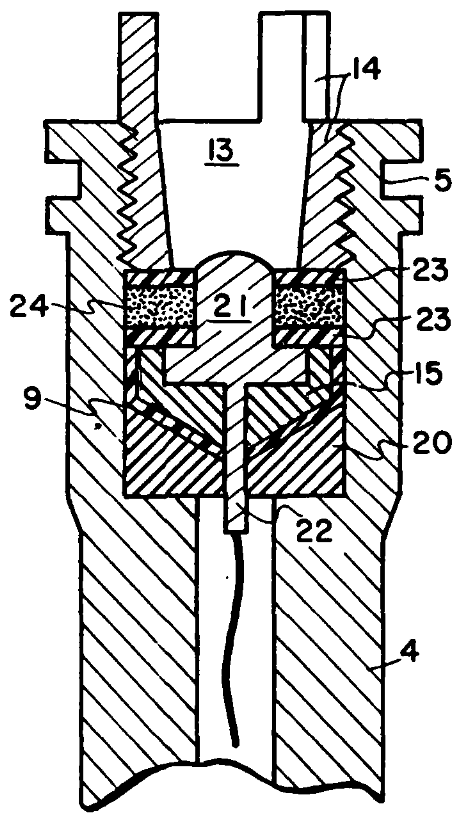
Primary Examiner—David H. Brown

Attorney, Agent, or Firm—R. S. Sciascia; W. Thom Skeer; T. W. Hennen

[57] **ABSTRACT**

An ignitor for a liquid propellant gun having a center electrode supported and surrounded by insulation so that only a planar or domed face is exposed. The assembly is firmly seated in the bolt nose of the gun and several outer electrode configurations with little or no precombustion area are disclosed.

13 Claims, 4 Drawing Figures



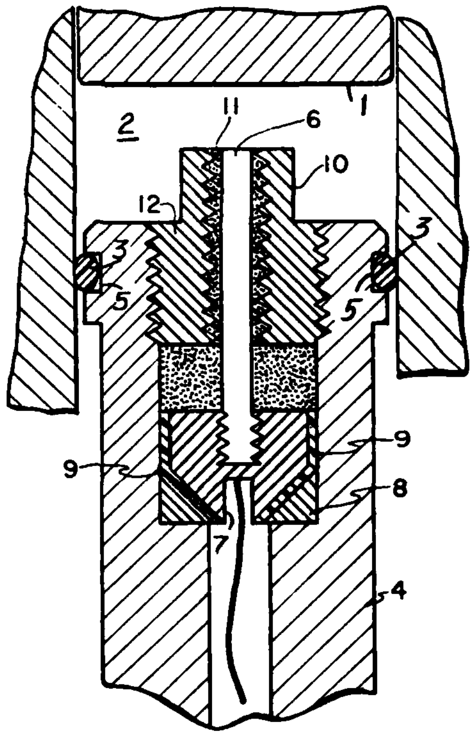


FIG. 1

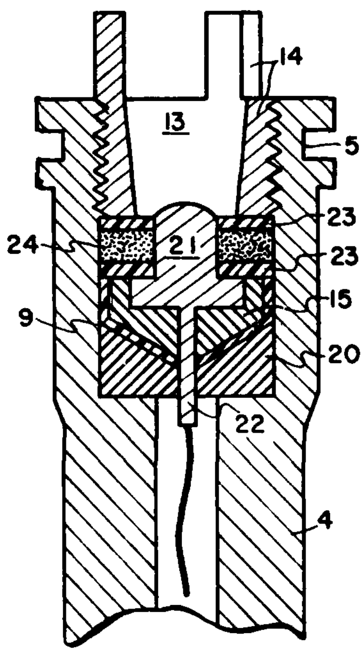


FIG. 2

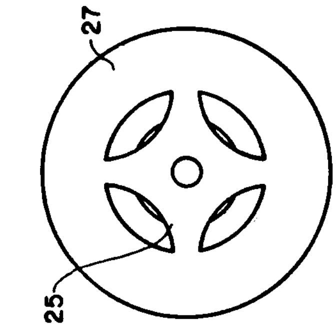


FIG. 3b

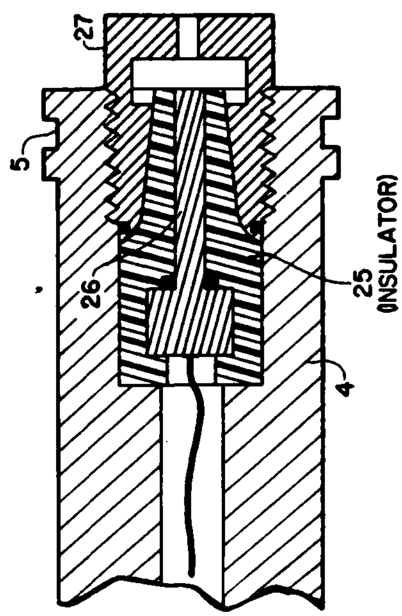


FIG. 3a

UNITED STATES PATENT AND TRADEMARK OFFICE
CERTIFICATE OF CORRECTION

PATENT NO. : 4,170,922

DATED : Oct. 16, 1979

INVENTOR(S) : Gary L. Peterson; Larry L. Liedtke

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

Item [75] should read

-- Gary L. Petersen; Larry L. Liedtke, both of Ridgecrest, Calif.

Signed and Sealed this

Eleventh **Day of** *March 1980*

[SEAL]

Attest:

SIDNEY A. DIAMOND

Attesting Officer *Commissioner of Patents and Trademarks*

IGNITOR

BACKGROUND OF THE INVENTION

1. Field of the invention

This invention relates to spark ignitors and more particularly to spark ignitors for liquid propellant guns.

2. Description of the Prior Art

A liquid propellant gun (LPG) is one in which a liquid propellant is burned in a firing chamber to propel a projectile from the gun. Such a gun uses a simpler projectile feed, has a flatter combustion chamber time-pressure characteristic, and more flexible installation and rapid fire features than a conventional gun. The liquid propellant, which may be either a monopropellant, or a fuel and an oxidizer, bipropellant is injected into the bore of the chamber, which is defined on one end by the base of the projectile and on the other by a bolt which a flattened end, termed the bolt nose. The bolt slides forward to seal the injection ports and position the projectile. To fire the LPG, the propellant is ignited by a pyrotechnic, thermal or electrical ignitor.

Previous electrical ignitors employed a center electrode which was free standing and projected into a small precombustion chamber to facilitate propellant ignition. These ignitors are subject to the bending of the center electrode due to pressure in the gun chamber, on the order of 60 Kpsi (411,700 Pa). Prior art ignitors also develop very high electrode temperatures and require frequent replacement. Test results have shown that prior art ignitors are also dependent on electrical polarity.

SUMMARY OF THE INVENTION

A sturdy, reliable ignitor for liquid propellant guns is installed in a standard bolt nose with a tubular center electrode anchored in a seat in the bolt nose and surrounded by insulation. The center electrode does not extend beyond the insulation except that if a rounded rather than flat face is used, the rounded portion should extend beyond the insulation. An annular outer electrode surrounds the inner electrode and either does not extend beyond the inner electrode or extends in such a fashion as to openly communicate with the combustion chamber.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a cross section view taken along the longitudinal axis of an ignitor according to the present invention wherein the center and outer electrodes form a planar surface extending beyond the bolt nose.

FIG. 2 is a cross section view taken along the longitudinal axis of an ignitor according to the present invention wherein the face of the center electrode is domed and slightly recessed in the bolt nose.

FIG. 3*a* is a cross section view taken along the longitudinal axis of an ignitor according to the present invention wherein the center electrode is on a plane with the bolt nose and the outer electrode extends slightly beyond the bolt nose.

FIG. 3*b* is an end view of the ignitor of FIG. 3*a* showing the webbed face of the outer electrode.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring now to FIG. 1, the ignitor of the present invention is installed in the nose of a standard liquid propellant gun (LPG) bolt 4. Gun bolt 4 is provided

with a groove 5 near the nose for an O-ring 3 which seals the bolt end of the combustion chamber. The combustion chamber of an LPG contains a bore 2 bounded on the barrel end of the gun by a projectile 1. The propellant is injected into the LPG chamber, the bolt slides forward and the propellant is ignited to propel the projectile.

The ignitor is thus in direct communication with the extreme temperature and pressure of the LPG chamber. To provide a sturdy ignitor, the center electrode 6 is threaded into a hard insulative seat 7, such as anodized aluminum, which rests on a copper seal 8 in an interior chamber of the bolt 4. Insulation between the seat 7 and the copper seal 8 is provided by the surface of the seat 7 and by a dielectric 9 which is preferably a shock-resistant material and preferably TEFLON ® tape. The outer electrode 10 is insulated from the rodlike portion of the inner electrode 6 by a shock-resistant insulator 11 such as TEFLON ®. TEFLON ®, polytetrafluoroethylene is a preferred insulator due to its relatively high strength, dielectric constant, thermal properties and resistance to acids such as nitric acid, commonly found in LPG oxidizers. It also is somewhat elastomeric and provides shock absorption, although it may tend to extrude from the assembly. Glass-filled TEFLON ® is therefore preferred to prevent extrusion. Insulator 11 has a base portion which rests on seat 7 and an elongted portion which extends along the length of and surrounds the center electrode 6. The elongated portion is provided with threads on its outer surface which mate with outer electrode 10. Outer electrode 10 has its outer surface threaded to match threads on the chamber in bolt 4 and its inner surface is threaded to receive insulator 11. When the insulator 11 is TEFLON ®, the threads in the inner surface of electrode 10 and on the insulator 11 help to secure the insulator and prevent extrusion during gun firing. Insulator 11 is loaded to about 40,000 psi (277,800 kPa) when the outer electrode is threaded into the assembly to seal the ignitor.

The outer electrode 10 thus surrounds the inner electrode 6 and is separated therefrom by the thickness of insulator 11. A center portion 12 of the outer electrode 10 extends, with insulator 11 and center electrode 6, slightly into the chamber (about 7 mm on a 30 mm LPG) to form a flush face surface consisting of the extended center portion 12 of outer electrode 10, insulator 11 and the flat end of center electrode 6.

The spark must therefore travel between inner electrode 6 and outer electrode 10 across a flush face. Field plots of constant voltage lines show high current densities between the electrodes in a flush face design. This shows a distorted electrical field effect which actually produces a single filament arc at lower voltages than free-standing electrode ignitors.

Using a solid state, silicon controlled rectifier, ignition circuit such as is described by the inventors in U.S. Pat. No. 4,104,920 filed 10 Feb. 1977, and hereby incorporated into the present specification, the ignitors described herein will fire at 50 volts whereas 700 volts have been required to fire other ignitors. As much as 3,000 volts may be used with the ignitors of the present invention although lower voltages are desirable, for example, in aircraft application. Twelve hundred to thirteen hundred volts is the preferred voltage range (compared to 1600 v with prior designs) and about 36–42 J is the preferred energy range at the electrodes. The use of higher energies, however, permits the use of

the present ignitors with monopropellants which are generally more difficult to ignite than bipropellants wherein the fuel and oxidizer are separately injected into the LPG chamber.

A number of design alternatives to the ignition as shown in FIG. 1 are possible. The flush face need not be extended into the chamber although this provides superior conduction by the propellant of the ignition and provides an ullage because the projectile is not flush against the bolt nose during propellant injection. The center electrode 6 and seat 7, rather than being threaded into each other, may be machined out of a single piece of stainless steel.

As stated, TEFLON® is a preferred dielectric. However, ceramics, anodized aluminum wherein the aluminum oxide surface provides the insulation, or other plastics may be used for insulation. From a purely structural standpoint, sapphire is the preferred dielectric. Ceramics and sapphire possess desirable heat transfer and structural properties so as to be equivalent for purposes of the present invention. For conductive members stainless steel is preferred. A pyrophoric material, such as tungsten, which blasts off small pieces during firing is also preferred for the center electrode, as this property aids in complete propellant ignition.

The present invention lacks a precombustion chamber, provides a sufficiently stable spark to cause ignition within the main volume of propellant, and eliminates compression problems of precombustors.

The embodiment of FIG. 2 retains a form of precombustor area 13. The outer electrode 14, rather than residing in a flush bolt face, presents a flush face with the insulator which is recessed into the bolt nose.

This embodiment, as shown in FIG. 2, uses a seat 15, insulation 9, and seal 20 similar to the extended flush face arrangement of FIG. 1. However, center electrode 21 presents a flush face with the insulator which is recessed into a chamber in the bolt nose.

The center electrode 21 has a rearward extension 22 for electrical connection through the bolt 4. The extension 22 is surrounded by a coaxial insulator for electrical insulation. The center electrode 21 has a base region for support in seat 15 and a domefaced cylindrical portion which is insulated by three dielectric rings. The outer dielectric rings 23 are preferably glass filled TEFLON® and sandwich a center ring 24 of Coors ceramic. The dielectric rings 23 or 24 abut the base region of the center electrode 21 and extend along the cylindrical portion so that only the domed face of the electrode is exposed in the precombustion area 13, whose sides are formed by outer electrode 14, which is threaded into the bolt nose to press on the ceramic discs and parts below. The ceramic discs should be machined to close tolerances to insure structural integrity of the ignitors. Beyond the bolt nose, three arms of the center electrode 14, two shown, project to reduce turbulence and allow free flow of the main porpellant charge. The propellant is enclosed only in the small area in the interior of the bolt nose and the cylindrical portion of the center electrode 21 is supported along its entire length by the insulating rings.

Referring now to FIG. 3, a further variation of the present invention has a tapered insulator 25 supporting the entire length of a center electrode 26 which is flush with the bolt nose. The outer electrode 27 however, extends beyond the bolt nose about 7 mm in a 30 mm LPG to form a small precombustor area and is capped, as shown in FIG. 3*b*, by a flat web which permits communication with the main propellant charge. The arc forms between the center electrode and the center of the web. Sharp edges and the small gap between the tip of the center electrode and the center of the web produce a distorted field effect which permits a low voltage spark.

In all of the foregoing embodiments, the center electrode may be positive or negative. In previous ignitors, significantly higher voltages were necessary if the center electrode was positive. The diameter of the center electrode, while not critical, is about 0.32 cm (⅛ inch) in a 30 mm LPG.

Voltage, electrode surface area, sharp edges and gap size may all be adjusted to yield the desired spark characteristics. The ignitors of the present invention having a flush face could be adapted for use in binary bombs, fuel-air explosives or the like.

What is claimed is:

1. An ignitor for a liquid propellant gun having a bore comprising:
- a bolt having a nose;
- a center electrode having a rodlike portion, a domed end and a broadened end anchored in said bolt at said broadened end;
- ring means for insulating said center electrode, surrounding and abutting the rodlike portion of the center electrode so that only the domed end is exposed to said bore;
- an outer electrode having a threaded portion anchored at one end in the bolt, abutting said ring means and surrounding said domed end of said electrode, said threaded portion extending beyond said domed end but not beyond said bolt nose; and
- means for transmitting electrical energy to said center electrode and connected thereto so as to cause a spark between said center and outer electrodes.

2. The ignitor of claim 1 wherein said ring means comprises a ceramic ring and a glass-filled polytetrafluoroethylene ring.

3. The ignitor of claim 1 wherein the outer electrode includes a plurality of arms extending beyond said bolt nose.

4. The ignitor of claim 1 wherein said ring means includes a ceramic ring.

5. The ignitor of claim 1 wherein said transmitting means includes an integral cylinderical extention of said center electrode extending away from said bolt nose.

6. The ignitor of claim 1 wherein said ring means includes two glass-filled polytetrafluoroethylene rings on either side of a ceramic ring.

7. An ignitor according to claim 1 wherein said domed and of said center electrode extends outwardly toward said bolt nose.

8. The ignitor of claim 1 further comprising an insulated seat for supporting said center electrode at the broadened end.

9. The ignitor of claim 8 wherein said outer electrode further comprises a plurality of arms extending beyond said bolt nose.

10. An ignitor according to claim 1 wherein said center electrode is recessed in a precombustion area having sides which are portions of said outer electrode.

11. An ignitor according to claim 10 wherein said domed end of the aforesaid center electrode extends in an outwardly convex fashion.

12. An ignitor according to claim 11 wherien the aforesaid outer electrode is configured to have a plurality of arms extending outwardly beyond said bolt nose.

13. An ignitor according to claim 11 wherein the aforesaid bolt has a circumfrential groove dimensioned to support an O-ring.

* * * * *

United States Patent [19]

Ayler et al.

[11] **4,172,408**

[45] **Oct. 30, 1979**

[54] **LIQUID PROPELLANT GUN, BREECH PRESSURE AXIAL INJECTION**

[75] Inventors: **Steve Ayler**, China Lake; **John Holtrop**; **Bruce Bartels**, both of Ridgecrest, all of Calif.

[73] Assignee: **The United States of America as represented by the Secretary of the Navy**, Washington, D.C.

[21] Appl. No.: **828,562**

[22] Filed: **Aug. 29, 1977**

[51] **Int. Cl.²** **F41F 1/04**

[52] **U.S. Cl.** **89/7**

[58] **Field of Search** 89/7

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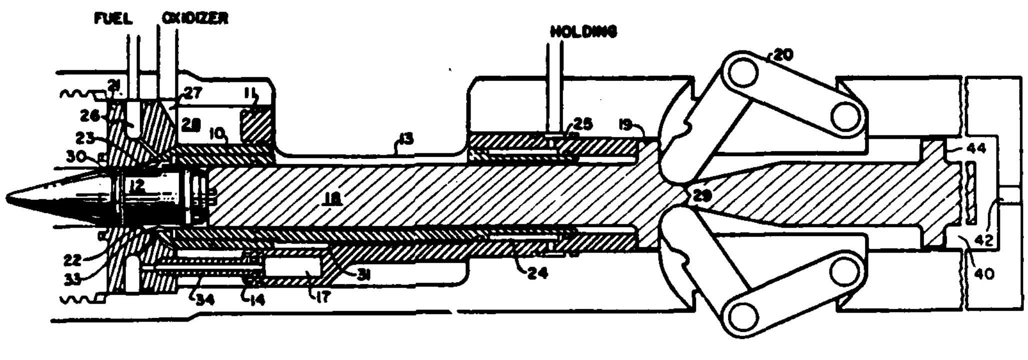
Primary Examiner—David H. Brown

Attorney, Agent, or Firm—R. S. Sciascia; W. Thom Skeer; K. G. Pritchard

[57] **ABSTRACT**

A liquid propellant gun having a chamber adapted to receive a projectile and liquid propellant and having a breech area containing a fuel injection system and a valve internally thereof and a bolt which is chambered within said valve and adapted to move from a projectile load to a fire position. The movement of the bolt from projectile load to fire position is done in one movement and this is possible in that the valve is able to hold high-pressure, making unnecessary a forward jogging of the bolt before firing.

7 Claims, 4 Drawing Figures



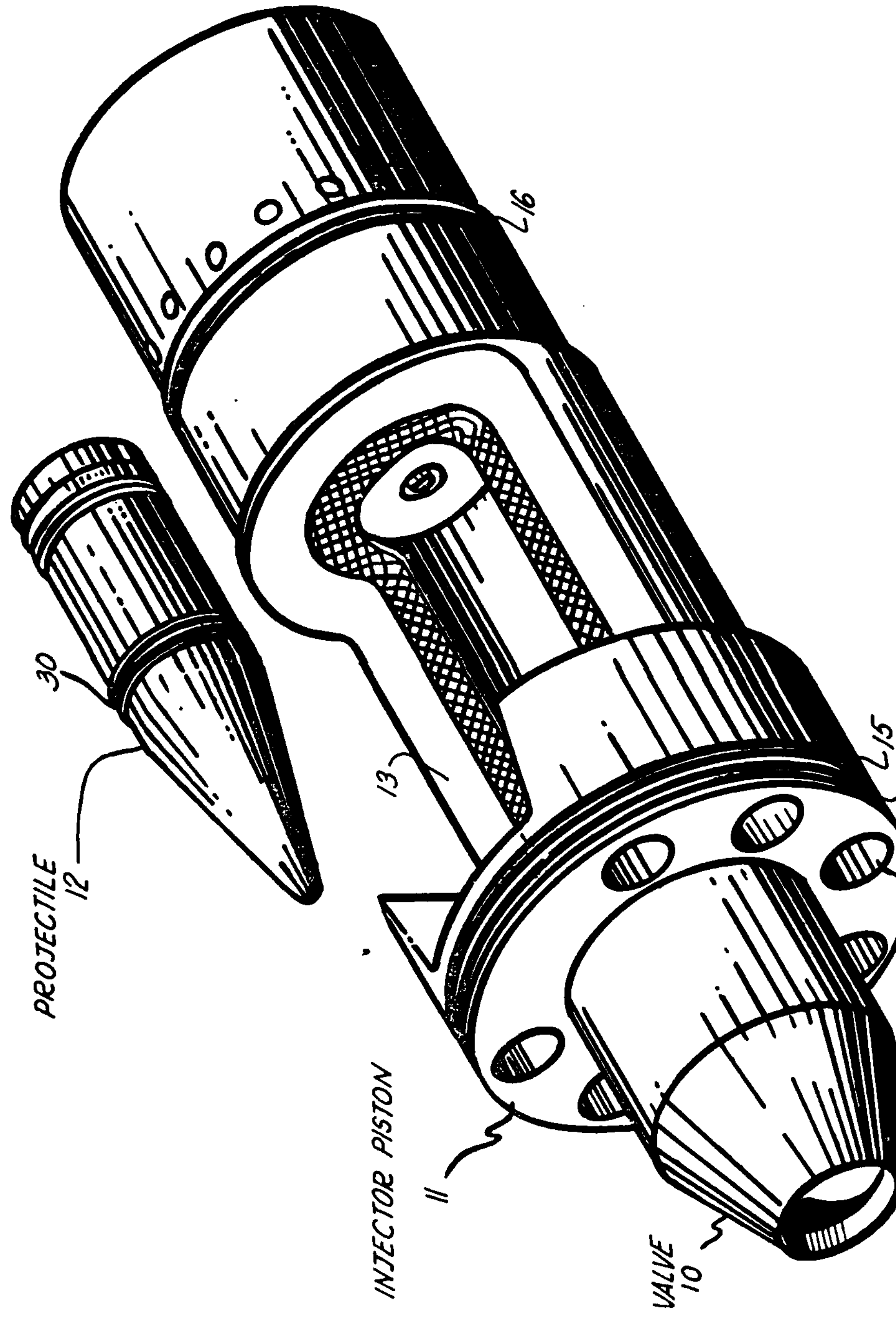


FIG. 1

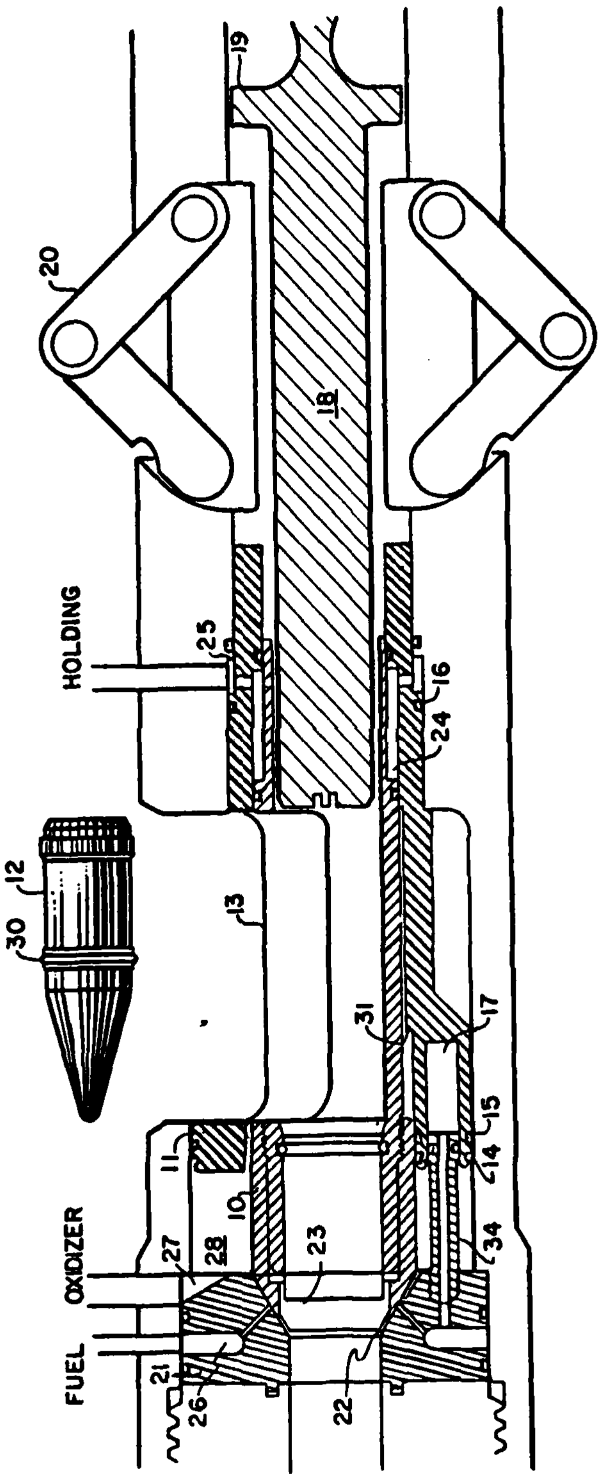

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FIG. 2

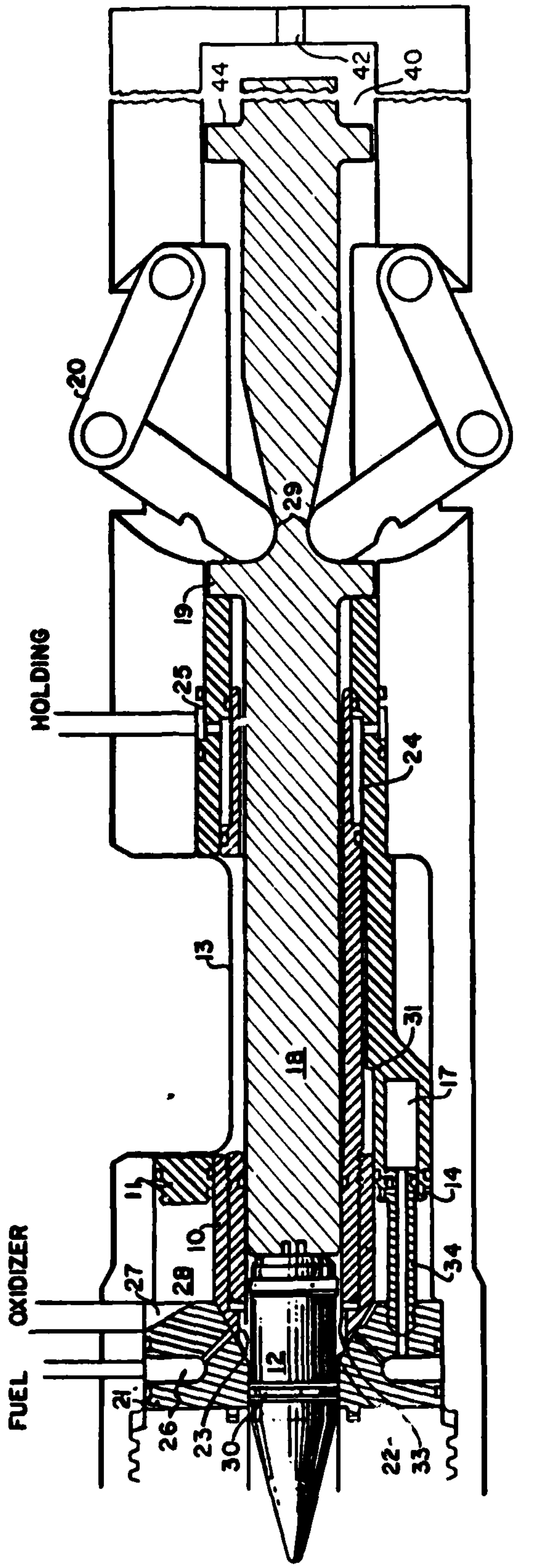
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FIG. 3

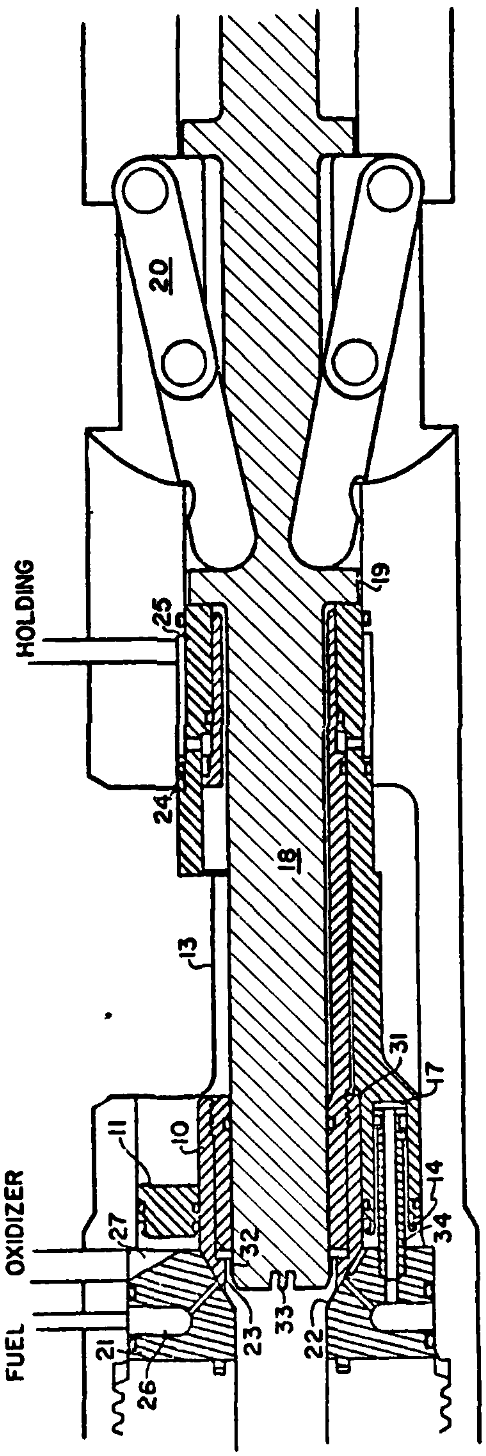

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FIG. 4

LIQUID PROPELLANT GUN, BREECH PRESSURE AXIAL INJECTION

BACKGROUND OF THE INVENTION

1. Field of the Invention:

The invention relates to liquid propellant guns and more specifically to an injection system for a liquid propellant gun wherein the valve and injector cooperate such that the valve is able to contain high-pressure. This feature of the valve allows the bolt to be moved smoothly from projectile load to fire position without a forward jogging of the bolt after the fuel and oxidizer have been injected and before firing.

In the past it has been necessary, with liquid propellant guns featuring dynamic propellant loading, to protect the propellant injection valve from high breech pressure. This was accomplished by jogging the bolt forward past the valve port following injection such that a seal on the bolt nose held the breech pressure away from the valve. Bolt jog motion however, complicates the overall gun mechanism.

Three separate actuators are required in that the motion of each major component occurs sequentially; injection first, jog second, and bolt lock third. A subsequent operation cannot proceed until the previous operation has been completed.

Such a system would have difficulty achieving the short cycle time necessary for an automatic gun with a high rate of fire.

2. Description of the Prior Art:

Examples of prior art liquid propellant guns are set forth in U.S. Pat. Nos. 3,922,976 and 4,005,632. U.S. Pat. No. 3,992,976 especially focuses on the problem intended to be overcome in the present invention wherein after injection the bolt is moved forwardly thereby translating the projectile, propellant charge and bolt mechanism forwardly until the end of the bolt is ahead of the injector. The bolt mechanism must then be stopped and locked thereby locking the gun before firing. This protects the injector but the bolt actuation and locking system is complicated and must be heavy enough to withstand firing pressures. Also, power requirements are high and the rate of fire is reduced as a consequence of the stop-start action.

SUMMARY OF THE INVENTION

The invention is primarily concerned with a novel valve and injector system wherein the bolt can be moved from projectile load to fire position in one stroke without the necessity for an intermediate stop and a jogging movement when the fuel and oxidizer are injected. This is accomplished by having a valve which is carried internally of an injector piston. The injector piston is moveable axially under the influence of a shoulder on the bolt which picks up the rear portion of the injector piston upon forward movement of the bolt. As the bolt is forced forward it moves the injector piston forward which causes propellant pressure to increase to "pop" the valve open. The valve opens by being moved rearwardly against a holding force. Propellant is then pumped through the valve, into the gun's chamber. The valve is then sealed before firing by having the bolt, on completion of its forward movement, act on a lip on the valve to force it into a closed position.

BRIEF DESCRIPTION OF THE DRAWING

FIG. 1 is an isometric view showing the valve, injector piston and projectile;

FIG. 2 is a cross-sectional view along the center axis of the rear portion of the liquid propellant gun in a projectile load position;

FIG. 3 is a cross-sectional view along the center axis of the liquid propellant gun in the inject position; and

FIG. 4 is a cross-sectional view along the center axis of the liquid propellant gun showing the mechanism in fire position.

DESCRIPTION OF THE PREFERRED EMBODIMENT

FIG. 1 is an isometric view of valve **10**, injector piston **11**, and projectile **12**. As shown in FIG. **1**, the injector piston is configured to contain the valve **10** internally thereof. The valve **10** and injector piston are cut away as at **13** to allow the projectile **12** to be chambered internally thereof.

The injector piston has a lip seal **14** and an O-ring seal **15** at the forward portion thereof and O-ring seal **16** at the rearward portion thereof taken with respect to FIG. **1**.

Small annular cavities as at **17** are formed at the forward portion of the injector piston **11**. The small annular cavities **17** are adapted to receive fuel during operation of the system.

Details of the entire assembly are more clearly shown in FIGS. **2**, **3**, and **4**. In FIG. **2**, the entire mechanism is in a projectile load position and shows a bolt **18** chambered internally of the valve **10** and having a shoulder **19** at the rearward portion thereof. Also shown is a toggle mechanism **20**, the purpose of which will become more clear as the explanation of moving the bolt from unload to load position is gone into. A manifold **21** is fixed internally in the bore of the liquid propellant gun and has a face **22** thereon which cooperates with a seal **23** at the forward end of the valve **10**. Carried by the manifold **21** are a series of individual injectors **34** which are received in the small annular spaces **17**.

Valve **10** is configured at the rear portion thereof to form a holding pressure chamber **24** which communicates through opening **25** with a holding fluid under pressure.

Fuel and oxidizer are introduced to the manifold **21** via ports **26** and **27** respectively. Oxidizer fills a large annular cavity **28** internally of the gun and externally of the valve **10** while fuel occupies the volume formed by the small annular cavities **17**.

The mechanism is shown in the projectile load position in FIG. **2** with again, oxidizer filling the large annular cavity **28** and fuel occupying the series of small axial cavities **17** within the injector piston **11**. The holding pressure applied through port **25** to the rear of the valve **10** keeps the valve closed. Projectile **12** is loaded through the area **13** in the valve and injector piston and stops in the valve just forward of the bolt **18**.

In FIG. **3**, bolt **18** and projectile **12** have been pushed forward until shoulder **19** on the bolt contacts the rear of the injector piston **11**. This forward movement is accomplished by hydraulic pressure in chamber **40** which is pumped in through access **42** and pushes against seal **44**. The double toggle bolt lock **20** has engaged the bolt **18** at the rear of shoulder **19**. A liquid seal **30** on the projectile **12** is seated within the bore of the manifold **21**.

LIQUID PROPELLANT GUN, BREECH PRESSURE AXIAL INJECTION

BACKGROUND OF THE INVENTION

1. Field of the Invention:

The invention relates to liquid propellant guns and more specifically to an injection system for a liquid propellant gun wherein the valve and injector cooperate such that the valve is able to contain high-pressure. This feature of the valve allows the bolt to be moved smoothly from projectile load to fire position without a forward jogging of the bolt after the fuel and oxidizer have been injected and before firing.

In the past it has been necessary, with liquid propellant guns featuring dynamic propellant loading, to protect the propellant injection valve from high breech pressure. This was accomplished by jogging the bolt forward past the valve port following injection such that a seal on the bolt nose held the breech pressure away from the valve. Bolt jog motion however, complicates the overall gun mechanism.

Three separate actuators are required in that the motion of each major component occurs sequentially; injection first, jog second, and bolt lock third. A subsequent operation cannot proceed until the previous operation has been completed.

Such a system would have difficulty achieving the short cycle time necessary for an automatic gun with a high rate of fire.

2. Description of the Prior Art:

Examples of prior art liquid propellant guns are set forth in U.S. Pat. Nos. 3,922,976 and 4,005,632. U.S. Pat. No. 3,992,976 especially focuses on the problem intended to be overcome in the present invention wherein after injection the bolt is moved forwardly thereby translating the projectile, propellant charge and bolt mechanism forwardly until the end of the bolt is ahead of the injector. The bolt mechanism must then be stopped and locked thereby locking the gun before firing. This protects the injector but the bolt actuation and locking system is complicated and must be heavy enough to withstand firing pressures. Also, power requirements are high and the rate of fire is reduced as a consequence of the stop-start action.

SUMMARY OF THE INVENTION

The invention is primarily concerned with a novel valve and injector system wherein the bolt can be moved from projectile load to fire position in one stroke without the necessity for an intermediate stop and a jogging movement when the fuel and oxidizer are injected. This is accomplished by having a valve which is carried internally of an injector piston. The injector piston is moveable axially under the influence of a shoulder on the bolt which picks up the rear portion of the injector piston upon forward movement of the bolt. As the bolt is forced forward it moves the injector piston forward which causes propellant pressure to increase to "pop" the valve open. The valve opens by being moved rearwardly against a holding force. Propellant is then pumped through the valve, into the gun's chamber. The valve is then sealed before firing by having the bolt, on completion of its forward movement, act on a lip on the valve to force it into a closed position.

BRIEF DESCRIPTION OF THE DRAWING

FIG. 1 is an isometric view showing the valve, injector piston and projectile;

FIG. 2 is a cross-sectional view along the center axis of the rear portion of the liquid propellant gun in a projectile load position;

FIG. 3 is a cross-sectional view along the center axis of the liquid propellant gun in the inject position; and

FIG. 4 is a cross-sectional view along the center axis of the liquid propellant gun showing the mechanism in fire position.

DESCRIPTION OF THE PREFERRED EMBODIMENT

FIG. 1 is an isometric view of valve **10**, injector piston **11**, and projectile **12**. As shown in FIG. **1**, the injector piston is configured to contain the valve **10** internally thereof. The valve **10** and injector piston are cut away as at **13** to allow the projectile **12** to be chambered internally thereof.

The injector piston has a lip seal **14** and an O-ring seal **15** at the forward portion thereof and O-ring seal **16** at the rearward portion thereof taken with respect to FIG. **1**.

Small annular cavities as at **17** are formed at the forward portion of the injector piston **11**. The small annular cavities **17** are adapted to receive fuel during operation of the system.

Details of the entire assembly are more clearly shown in FIGS. **2**, **3**, and **4**. In FIG. **2**, the entire mechanism is in a projectile load position and shows a bolt **18** chambered internally of the valve **10** and having a shoulder **19** at the rearward portion thereof. Also shown is a toggle mechanism **20**, the purpose of which will become more clear as the explanation of moving the bolt from unload to load position is gone into. A manifold **21** is fixed internally in the bore of the liquid propellant gun and has a face **22** thereon which cooperates with a seal **23** at the forward end of the valve **10**. Carried by the manifold **21** are a series of individual injectors **34** which are received in the small annular spaces **17**.

Valve **10** is configured at the rear portion thereof to form a holding pressure chamber **24** which communicates through opening **25** with a holding fluid under pressure.

Fuel and oxidizer are introduced to the manifold **21** via ports **26** and **27** respectively. Oxidizer fills a large annular cavity **28** internally of the gun and externally of the valve **10** while fuel occupies the volume formed by the small annular cavities **17**.

The mechanism is shown in the projectile load position in FIG. **2** with again, oxidizer filling the large annular cavity **28** and fuel occupying the series of small axial cavities **17** within the injector piston **11**. The holding pressure applied through port **25** to the rear of the valve **10** keeps the valve closed. Projectile **12** is loaded through the area **13** in the valve and injector piston and stops in the valve just forward of the bolt **18**.

In FIG. **3**, bolt **18** and projectile **12** have been pushed forward until shoulder **19** on the bolt contacts the rear of the injector piston **11**. This forward movement is accomplished by hydraulic pressure in chamber **40** which is pumped in through access **42** and pushes against seal **44**. The double toggle bolt lock **20** has engaged the bolt **18** at the rear of shoulder **19**. A liquid seal **30** on the projectile **12** is seated within the bore of the manifold **21**.

At this point, propellant injection begins. Bolt 18 continues traveling forward thereby exerting a force on the rear of the injector piston 11. This raises the propellant pressures in cavities 28 and 17. The increased pressure exerts a force on the forward end of the valve which overcomes the valve holding force in chamber 24 and "pops" valve 10 open by moving it rearwardly with respect to the injector piston 11. Thus it can be seen that valve 10 is a tension closed fitting that only opens when the internal pressure exceeds a predetermined amount.

As the bolt 18 and injector piston 11 travel forward as a unit, propellant is pumped into the sealed cavity behind the projectile 12 thereby pumping the projectile forward with respect to the bolt 18. Near the end of the injection, a step 31 on the inside diameter of the injector piston contacts the valve 10 and forces it closed thereby ending injection.

In FIG. 4, the gun is in fire position. The double toggle 20 holds all of the moving parts of the mechanism in a tightly locked position. A lip seal at 32 uses breech pressure to form a tight seal around the bolt 18 and a second lip seal at 22 seals the injection port in a like manner. With the bolt slightly larger in diameter than the chamber, breech pressure exerts a forward closing force on the valve. This sealing means prevents back pressure damage to the valve, fluid injection means or the chamber behind the bolt. A spark provided at 33 ignites the propellant, causing the projectile 12 to be forcibly ejected from the gun.

The prime advantage of the present system over previous designs is the integration of injection, bolt, and bolt lock functions into simultaneous or smooth rather than sequential operations. In an automatic gun, this will mean shorter cycle time with lower power requirements. By intermittently coupling the bolt and injector piston, the number of actuators is dropped from 3 to 2, bolt and bolt lock.

The major new feature making this possible is the breech pressure valve. With this valve able to hold high-pressure, the need for bolt jog is eliminated. The bolt travel and injection operations can then be coupled together and terminated at the same time. Another new feature of the present invention, is the porting of the valve holding pressure through the injector piston in a manner that exerts no net force on the piston.

The breech pressure valve might be configured alternatively such as the bolt in its locked position bearing on the valve directly but behind the injection port. Breech pressure is allowed to enter the area but its held by a lip seal surrounding the bolt. Since the bolt is configured slightly larger in diameter than the chamber, the high pressure exerts a strong closing force on the valve. Fuel and oxidizer might then be delivered to the valve from a pump located elsewhere in the gun.

What is claimed is:

1. In a liquid propellant gun having a chamber adapted to receive a projectile and liquid propellant the combination comprising:
- a gun having a rear portion with a substantially cylindrical hollow breech area having a central axis;
- fluid injector means contained within the breech area and having a central axis co-extensive with the axis of the breech area for insecting liquid propellant into said chamber;
- valve means contained within the breech area and also having a central axis co-extensive with the axis of the breech area for regulating the injection of said liquid propellant in a predetermined manner;
- a bolt contained within said breech area and having a central axis co-extensive with the axis of the breech area and having unloaded and loaded positions;
- means for moving said bolt forward from an unloaded to a loaded position; said bolt and fluid injector means cooperating such that when said bolt is moved from the unloaded to the loaded position the fluid injector means is carried along therewith and said valve means is caused to open thereby forcibly injecting liquid propellant into the chamber of said liquid propellant gun duing the initial movement of said bolt forward and where said valve means is closed and sealed upon said bolt reaching its farthest advance such that said gun may be fired without forward jogging of said bolt.

2. In a liquid propellant gun as set forth in claim 1 wherein;
- said fluid injector means and said valve means have an opening therein adapted to receive a projectile for loading into the chamber of said propellant gun.

3. In a liquid propellant gun as set forth in claim 2 wherein;
- said fluid injector means lies outside and around said valve means.

4. A liquid propellant gun as set forth in claim 1 wherein said fluid injector means comprises:
- a hollow piston slideably mounted in a cylinder surrounding said valve means so as to be carried in a compression stroke when said bolt advances a projectile in said chamber, where the chamber of said liquid propellant gun has a tension closed fitting with said piston which is opened to permit liquid propellant into said chamber when said piston compresses fluid within said hollow piston beyond a predetermined pressure; and
- a step on the inside diameter of said piston for closing said valve means when said piston is at the end of its compression stroke.

5. A liquid propellant gun as set forth in claim 4 further comprising a manifold for injecting either fuel or oxidizer to said chamber through an opening on a face of said manifold where said face forms one surface for the tension closed fitting between said chamber and said piston.

6. A liquid propellant gun as set forth in claim 5 further comprising:
- a lip seal on said manifold face within said chamber for supporting high pressure in said chamber that does not backup into said fluid injector means such that further advancement of said bolt in said chamber to prevent such back pressure is not required; and
- a seal on said bolt for preventing high pressure in said chamber during firing from backing around said bolt.

7. A liquid propellant gun having a chamber adapted to receive a projectile and liquid propellant in the form of fuel and oxidizer comprising:
- a substantially cylindrical hollow breech area having a central axis for loading a projectile into said chamber;
- fluid injector means contained within said breech area and having a central axis co-extensive with the axis of said breech area for injecting liquid propellant into said chamber;

a bolt contained within said chamber for advancing a projectile forward from its initial placement in said chamber through said breech area;

means for moving said bolt forward in said chamber located in the rear portion of said chamber;

valve means contained within said breech area and also having a central axis co-extensive with the axis of said breech area for regulating the flow of fuel and oxidizer into said chamber in a predetermined

manner, said valve means, fluid injector means and bolt cooperating such that when said bolt advances a projectile forward said fluid injector means pumps liquid propellant between said projectile and said bolt through said valve means; and

sealing means within said chamber for preventing back pressure through said valve means or around said bolt.

* * * * *

U.S. AIR FORCE PATENTS

Patent Number: 3,690,255
Author: Edward J. Vass, Los Alamitos, CA; Richard H. Braun, Downey, CA; Conrad R. Platt, Huntington, CA
Title: Liquid Propellant Cartridge
Date: September 12, 1972

United States Patent [15] 3,690,255

Vass et al. [45] Sept. 12, 1972

[54] LIQUID PROPELLANT CARTRIDGE

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[73] Assignee: The United States of America as represented by the Secretary of the Air Force

[22] Filed: Oct. 1, 1970

[21] Appl. No.: 77,160

[52] U.S. Cl. 102/39, 89/7, 60/26.1

[51] Int. Cl. F42b 3/04

[58] Field of Search 60/218, 26.1, 39.48; 89/7; 81/1; 102/39

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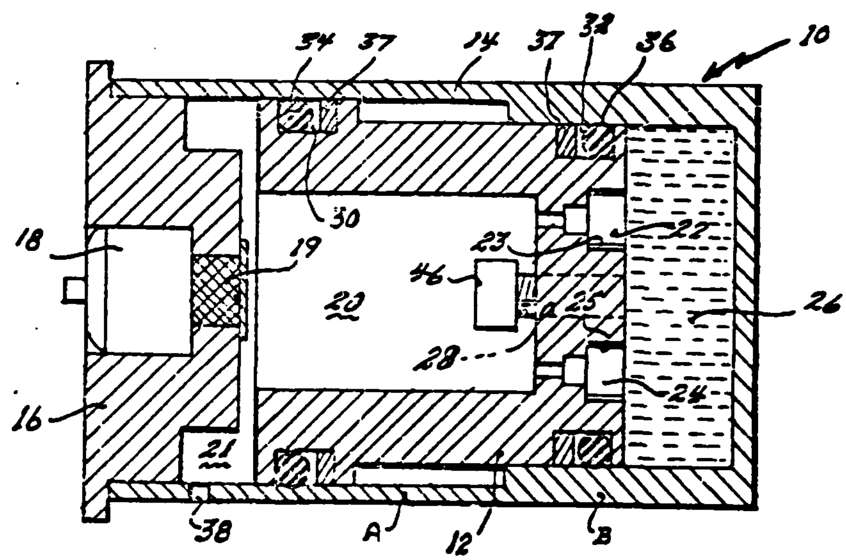
Primary Examiner—Samuel W. Engle
Attorney—Harry A. Herbert, Jr. and Ruth G. Codier

[57] ABSTRACT

A system for controlled generation of high energy gas from a liquid propellant, based upon a differential area piston injecting liquid propellant into a combustion chamber in a regenerative cycle. One of its applications is for cartridge bomb ejection. Pressure of burning fuel fired by a primer ruptures seals in a piston wall and causes extrusion of liquid fuel from a reservoir area into the piston cavity which lies in the combustion area. Combustion of the extruded liquid carries on a regenerative process until all fuel in the reservoir has been consumed.

1 Claim, 5 Drawing Figures



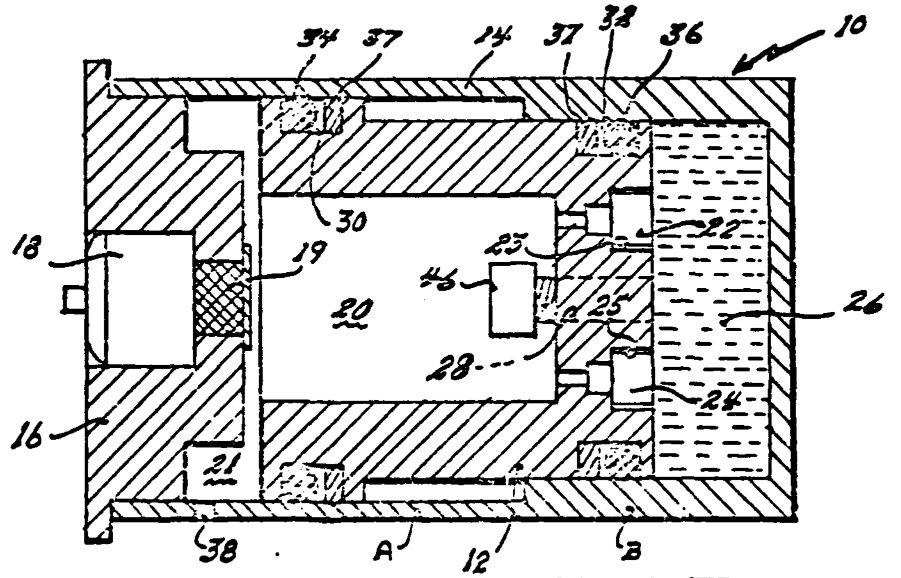
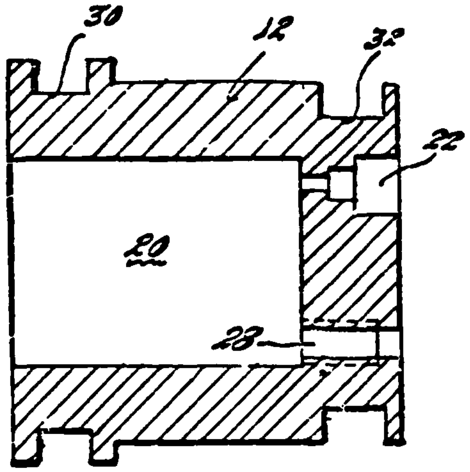


FIG.1



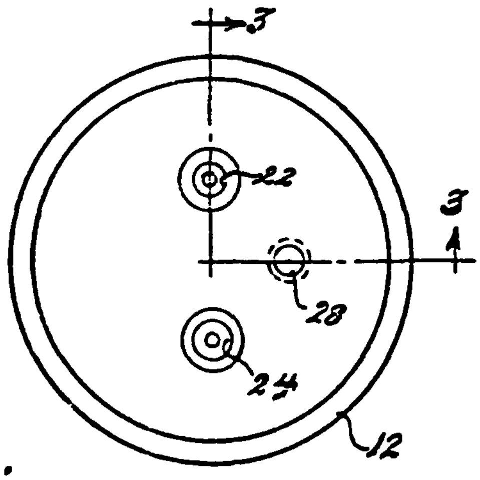


FIG.3

FIG.2

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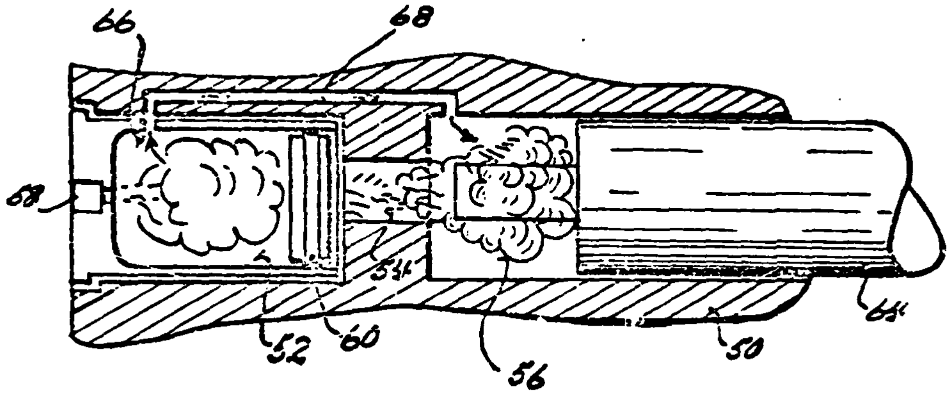
FIG. 4



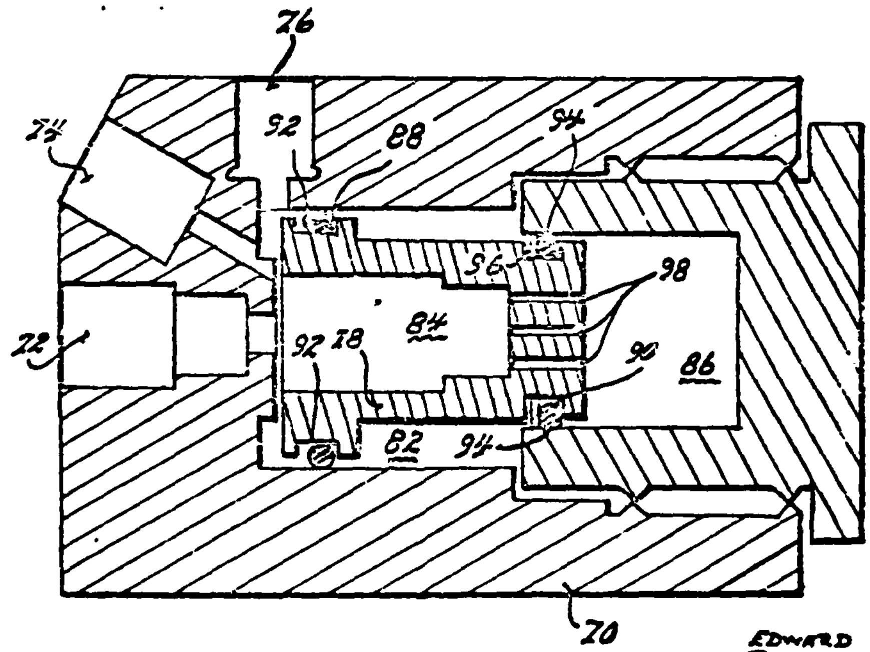


FIG. 5

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LIQUID PROPELLANT CARTRIDGE

BACKGROUND OF THE INVENTION

This invention relates to a system for controlled generation of high energy gas from a liquid propellant, and more particularly to a device which includes a differential area piston for a liquid propellant cartridge in a bomb ejection system.

Difficulty has been experienced in controlling combustion rates. Systems were proposed based on a regulated flow of liquid propellant from a two chamber cartridge. This was expected to extend the burn time of the liquid propellant to achieve relatively long, low-pressure time curves. The liquid propellant was ignited with a primer in the first of the two chambers. The combustion in the first chamber located next to the primer was expected to exert a pressure on a movable piston which, in turn, pressurized the liquid propellant in a second chamber and ejected it into a combustion area. The rate at which the liquid burned in the combustion chamber regulated the flow rate of the liquid through the orifice connecting the two chambers. The time of orifice opening was expected to be controlled by a differential piston connected directly to the material to be ejected. Ignition of the liquid from the second chamber was expected to be accomplished by flame bleedoff into a pass channel from the first chamber.

The problem with this approach is typical of any concept dependent on the confined burning of bulk liquid propellant. The burning rate cannot be controlled as it is a function of the liquid's surface area. As ignition and burning of the liquid take place, the surface area of the liquid increases rapidly in a random manner to the extent that the burning process can occur at the detonation rate of the liquid.

Other difficulties arose. Erosion became a problem. Contamination occurred, particularly aluminum particles injected from the cartridge case into the bomb rack system.

Furthermore, normal propyl nitrate (NPN), a liquid propellant in general use, is incompatible with many plastics and metals. Good sealing methods were difficult to accomplish.

SUMMARY OF THE INVENTION

The objects of the invention are therefore, to provide a regenerative system and a device which will:

a. reduce reactive forces by controlling the combustion rate of the liquid propellant;

b. increase the mean time between ejection-system failures by using a liquid propellant having a low-combustion temperature, thus decreasing erosion;

c. reduce system contamination by decreasing residue through using liquid propellants and by minimizing the quantity of aluminum particles injected from the cartridge case into the system; and

d. enable the system to withstand high temperatures. Epoxy adhesive and polythelane plugs are to be used in the piston orifices. Ethylene propylene and Teflon are used for 0-rings and piston seals. The piston casing is a one-piece steel case.

These and other advantages, features and objects of the invention will become more apparent from the following description taken in connection with the illustrative embodiments in the accompanying drawings.

DESCRIPTION OF THE DRAWINGS

FIG. 1 is a longitudinal sectional view of the cartridge assembly;

FIG. 2 is a diagrammatic view of the piston face showing the location of the fill hole and extrusion orifices;

FIG. 3 is a longitudinal sectional view of the piston removed from the casing and taken on the line 3—3 of FIG. 2;

FIG. 4 is a longitudinal sectional view of a modification of the device. It is the original concept from which the preferred embodiment of FIGS. 1, 2 and 3 was developed; and

FIG. 5 is a breech assembly incorporating a modified cartridge.

DESCRIPTION OF THE PREFERRED EMBODIMENT

The cartridge assembly is indicated generally by the numeral 10. A differential area piston 12 is assembled into a casing 14 and sealed into place by a closure 16. A primer assembly 18 is located in a bore in the closure 16. The bore extends completely through the closure 16, accommodating also the ignition mix 19, when function is to ignite the liquid propellant within a first chamber 20. The piston 12, the casing 14, and the closure element 16 are fabricated of heat-treated steel for strength and resistance to erosion. The piston 12 has a free-volume internal cavity 21 to reduce the initial combustion pressure. A pair of orifices, 22 and 24, provide a metering entrance of the liquid burning material from the second chamber 26 to the first chamber 20. The opening 28 functions as a fill hole. The piston 12 is provided with grooves or recesses 30 and 32 to accommodate the 0-rings 34 and 36. The recesses, 30 and 32, also accommodate the retaining rings 37. The casing 14 has two areas A and B with a differential internal diameter. The piston 12 has a corresponding differential in external diameters to fit within areas A and B of the casing 14, thus forming the chambers 20 and 26.

The first or combustion chamber 20 is provided with an exhaust port orifice 38. The closure 16 has an annular shoulder which aligns the assembly 10 when inserted into a cartridge holder (not shown).

Since the liquid propellant normal propyl nitrate or NPN which is used is incompatible with many plastics and metals, the orifices 22 and 24 in the piston 12 are sealed with epoxy adhesive and polyethylene plugs or aluminum tape.

The 0-rings 34 and 36 are of ethylene propylene, or comparable material and the retaining rings 37 are Teflon.

After the piston 12 has been inserted into the steel casing 14 the liquid propellant is inserted through the hole 28. The method used is to inject the liquid through the hole 28 by means of a hypodermic needle and syringe so that any entrapped air will bleed back through the hole. The quantity of fuel injected is measured and the hole sealed when the operation is completed.

The closure plug 16 containing the primer assembly 18 is sealed onto the casing 14 with an epoxy seal.

The polyethylene plugs or aluminum tape used to cover the holes 22 and 24 rupture when the movement

of the piston applies sufficient pressure against the NPN in the reservoir cavity 26. Until the proper pressure is applied, all of the NPN is contained in the cartridge case 14 and held within the reservoir 27, since the cavity 26 is sealed by the piston 0-ring 36. The cavity 20 which is the combustion chamber is sealed by the piston 0-ring 34, by the taped orifice 38 and the screw 46 closing the orifice 28.

When the pressure caused by the initial firing reaches a predetermined level the sealing material of the orifices 22 and 24 rupture. The pressure of the piston 12 against the NPN causes extrusion of NPN into the chamber 20. The bores 22 and 24 are provided with counterbores 23 and 25 at the NPN piston surface into which the sealing material can lodge without clogging the orifice.

MODE OF OPERATION

The liquid propellant cartridge functions in the following sequence:

Upon application of a firing pulse from a power supply (not shown) the pyrotechnic mixture 19 within the primer 18 ignites. Gas pressure and burning particles accumulate in the cavity 20 at the large end of the piston, and adjacent the primer 18. The cavity is designed to provide free volume for gas expansion to reduce the peak pressure. Some of the gas escapes through the exhaust port orifice 38. Simultaneous with this application of pressure, a reactive pressure greater than that existing in the first chamber 20 is created at the small end of the piston 12 in the reservoir chamber 26. This pressure differential is sufficient to cause the seals of the orifices 22, 24 and 28 to rupture, freeing the liquid fuel in the reservoir chamber and allowing it to flow through these orifices. The flow rate is regulated by the orifice size, the exhaust port size, and the differential pressure. As the liquid enters the cavity 20, it is initiated and combusts.

The piston 12 is moved against the NPN by the initial pressure of the primer and is sustained by the combustion of the liquid in the cavity 20. This causes the liquid to again be extruded through orifices 22, 24, passing from the reservoir chamber 26, through the piston orifices and into the combustion chamber 20. The residual combustion produced from the primer 18 again initiates the extruded liquid and it combusts at the large end of the piston in the cavity 20. This creates pressure in addition to that provided by the primer, regenerating the process until all the liquid in the reservoir 26 is extruded and consumed.

Referring now to FIG. 4, this Figure is a representation of the original form of the device from which the preferred embodiment was developed.

In this embodiment, there is achieved a regulated flow of liquid propellant from a cartridge 50 provided with a pair of chambers 52 and 54 and a combustion chamber 56. In this device the burn time of the propellant was extended and relatively long, low pressure time curves were achieved. The liquid propellant is ignited with a primer 58 in the first chamber 52. The combustion in this chamber exerted pressure on the movable piston 60. With the movement of the piston 60 the liquid propellant in the second chamber 54 ejects it into the combustion area 56. The rate at which the liquid burns in the combustion chamber 56 regulates the flow rate of the liquid through the passage chamber 54. The time of passage 54 opening is controlled by a differential piston 64 connected directly to the stores (not shown) to be ejected.

Ignition of the liquid from the second chamber 56 is accomplished by a flame bleed off 66 into a by-pass channel 68.

Referring now to FIG. 5, a breech assembly 70 has a primer recess 72, a transducer port 74 and an exhaust port 76. A piston 78 provides a cavity 84 and separates a first chamber 82 from a combustion chamber 86. Recesses 88 and 90 house 0-rings 92 and 94 and a back-up ring 96.

Openings 98 provide a regulating flow from piston cavity area 84 to the combustion chamber 86.

In the operation of this device a regenerative process takes place as described above in the operation of the device of the preferred embodiment

Although the invention has been described with reference to particular embodiments, it will be understood to those skilled in the art that the invention is capable of a variety of alternative embodiments within the spirit and scope of the appended claims.

We claim:

1. A system for controlled generation of high energy gas from a liquid propellant comprising:
   - a cylindrical casing having differential areas along its length,
   - a close-fitting differential piston slidably disposed in said cylindrical casing,
   - a reservoir chamber in said casing forward of said differential piston,
   - a combustion chamber in the central area of said differential piston,
   - a closure element fixedly attached to the rearward end of said casing for effectively sealing said combustion chamber,
   - a primer housed in a recess in said closure element, said primer being in operative communication with said combustion chamber,
   - a plurality of orifices in the closed forward end of said differential piston in communication with said reservoir chamber, said orifices being dimensioned to control the rate of flow of propellant into said combustion chamber,
   - rupturable seals covering each of said orifices, and
   - a vent opening in said casing between said piston and said closure element, said vent opening having a rupturable seal thereover for regulating the pressure in said combustion chamber,
   - whereby the firing of said primer causes pressure to build up in said combustion chamber and rupture the vent opening seal while urging the piston forward until the seals covering the orifices in said differential piston are ruptured allowing liquid propellant in the reservoir chamber to pass into the combustion chamber at a controllable rate and be ignited by the residual combustion of the initial firing of said primer, thereby creating additional pressure and regenerating the process until all of the propellant in the reservoir chamber has flowed into the combustion chamber and been consumed.

* * * * *

OLIN MATHIESON CORPORATION PATENTS

Patent Number: 2,922,341
Author: J. W. Treat, Jr.
Title: Projectile Propelling System
Date: January 26, 1960

Patent Number: 2,947,221
Author: D. N. Griffin, et al
Title: Compression Ignition Gun
Date: August 2, 1960

Patent Number: 3,195,407
Author: C. F. Turner
Title: Liquid Propellant Projectile Unit
Date: July 20, 1965

Patent Number: 3,202,055
Author: D. F. Butler, et al
Title: Valve System for Compression Ignition Device
Date: August 24, 1965

Patent Number: 3,455,202
Author: G. R. Dixon, et al
Title: Liquid Propellant - Actuated Device
Date: July 15, 1969

Jan. 26, 1960 J. W. TREAT, JR 2,922,341

PROJECTILE PROPELLING SYSTEM

Filed Nov. 7, 1955 4 Sheets-Sheet 1

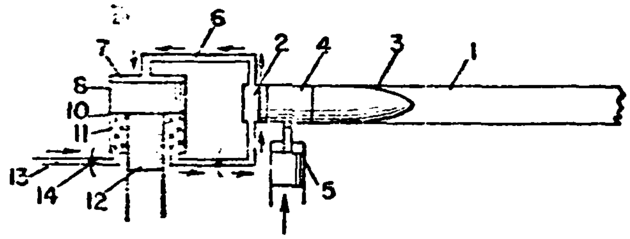

FIGURE 1

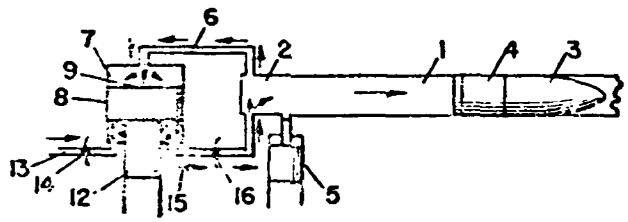

FIGURE 2

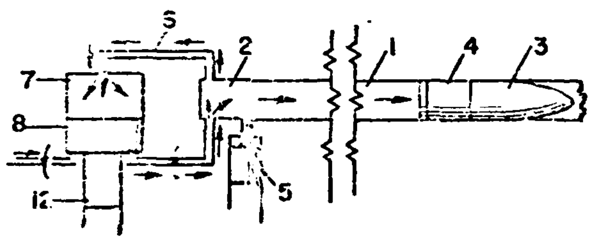

FIGURE 3

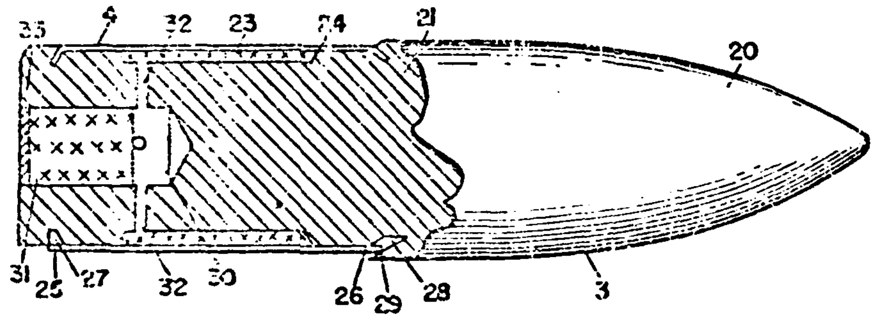

FIGURE 4

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PROJECTILE PROPELLING SYSTEM

Filed Nov. 7, 1955 4 Sheets-Sheet 2

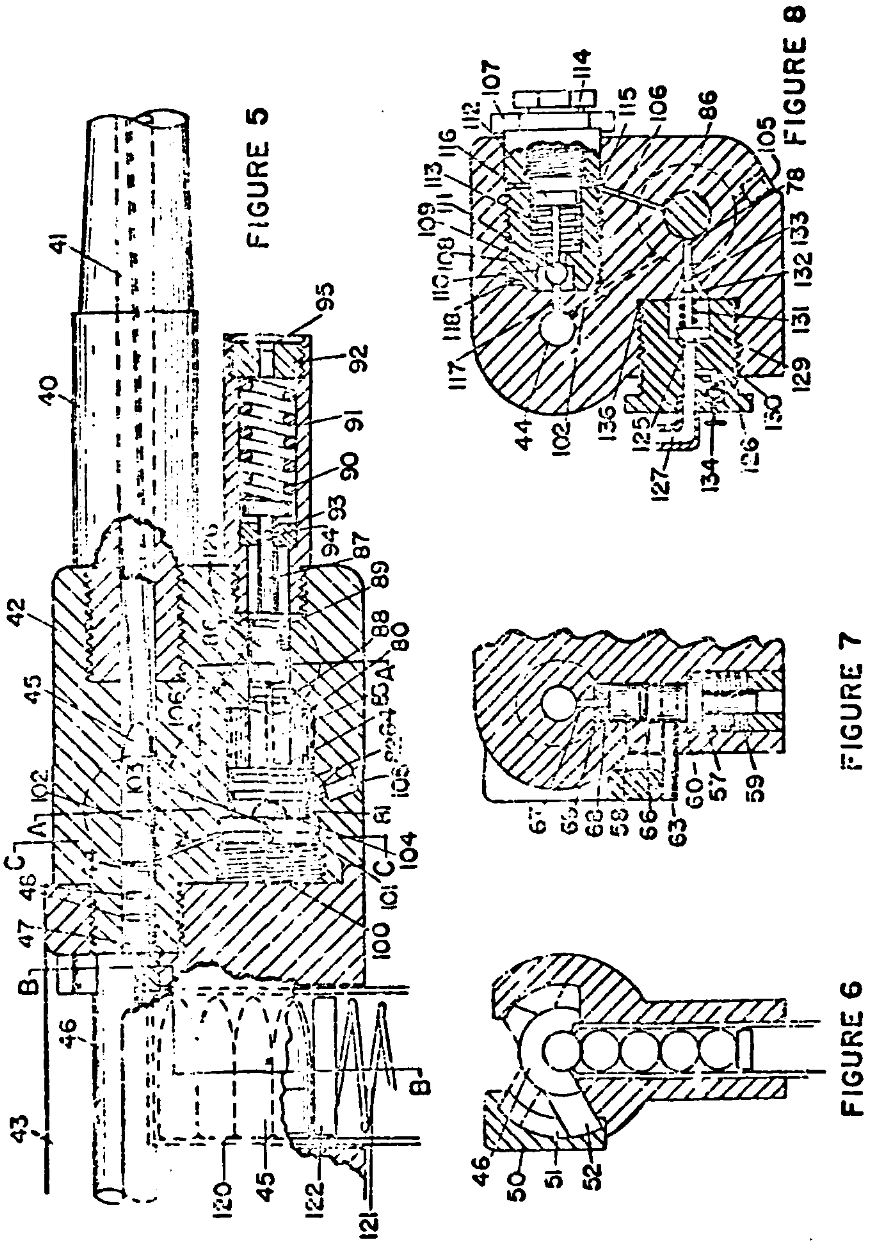

FIGURE 5

FIGURE 6

FIGURE 7

FIGURE 8

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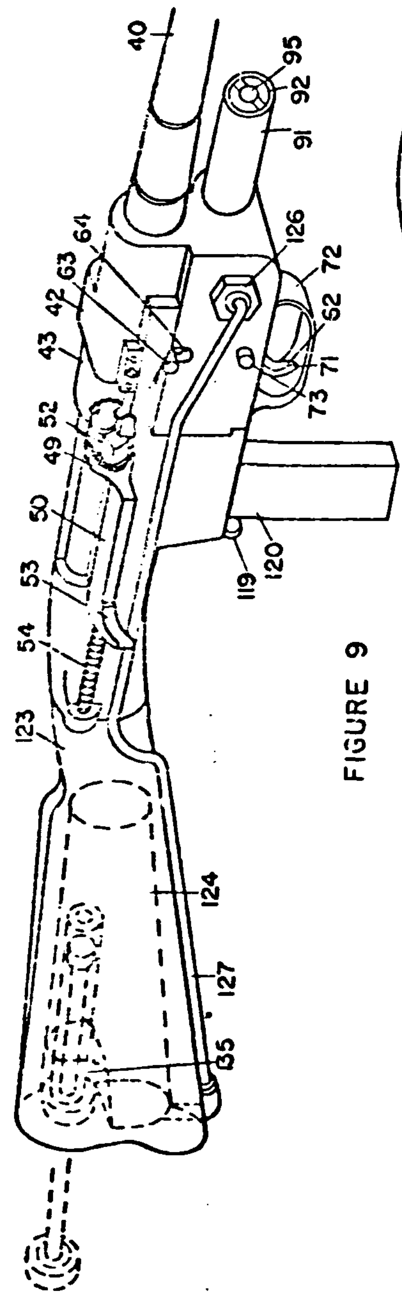

FIGURE 9

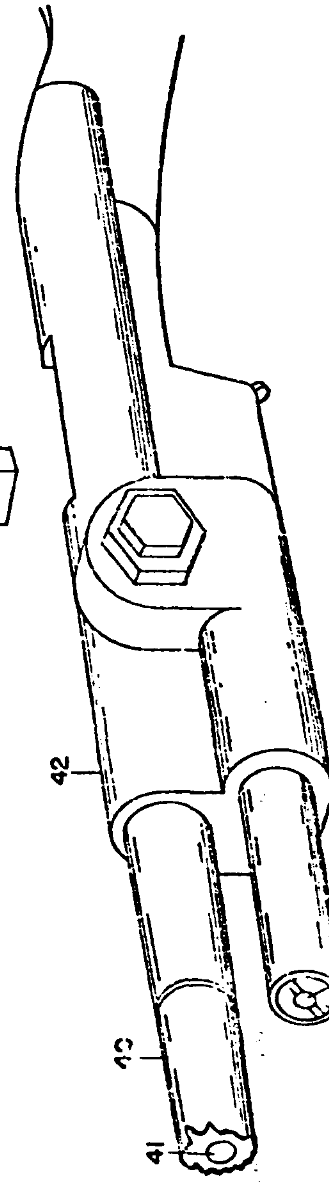

FIGURE 10

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PROJECTILE PROPELLING SYSTEM

Filed Nov. 7, 1955 4 Sheets-Sheet 4

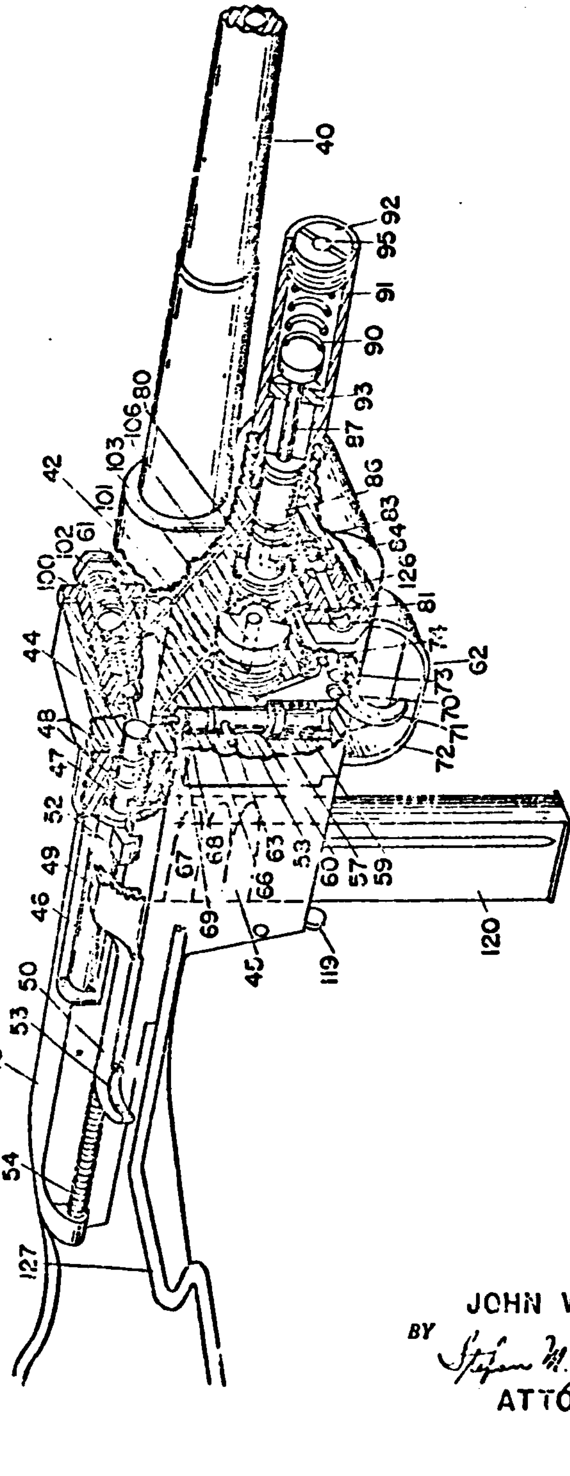

FIGURE 11

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2,922,341

PROJECTILE PROPELLING SYSTEM

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Application November 7, 1955, Serial No. 545,290

3 Claims. (Cl. 89—7)

This invention relates to an improved method and means for propelling a projectile with a liquid propellant and more particularly to a gun system capable of using liquid mono-propellant regeneratively injected into an initially dry chamber by pneumatic means initiated by a primer.

Heretofore, firearms employing liquid propellants generally were open-ended chambers, the open end being sealed by a caseless projectile. A liquid propellant having a high vapor pressure would be pumped into the chamber and then the mixture was ignited, generally with a spark plug to drive the projectile down the bore and out the muzzle of the gun. (See U.S. 1,343,456 and U.S. 1,359,295.) Due to difficulties in sealing the liquid propelalnt within the chamber and in ignition, these guns have never become popular. Solid propellant type guns employing cased ammunition, the case containing a percussion type primer were more popular because they were simpler and more convenient to use and required less complicated gun actions.

Several features possible with liquid propellants have, nevertheless, obviated complete abandonment of the production of liquid propellant type guns. The ease in storing and loading, the lack of a need for grain formation, the possibility of an easier means for effecting progressive burning or regenerative injection similar to that disclosed in U.S. 1,297,798 or U.S. 2,360,217 for solid propellants and other attractive features of a liquid propellant gun have always been the deterrent against its complete abandonment. But heretofore a successful gun system never proved feasible.

An object of this invention is to provide a novel method and means for propelling a projectile with a liquid propellant. Another object of this invention is to provide a propellant system for a firearm capable of using a mono-propellant as its main charge. Another object of this invention is to provide a propellant system embodying regenerative injection of the propellant so as to accomplish energy utilization of a high degree. A further object of this invention is to provide a propellant system having an adjustable regenerative injection rate. A further object of this invention is to provide a firearm using a liquid propellant with pyrotechnic ignition. Another object of this invention is to provide a firearm which commences operation from a dry chamber. Another object of this invention is to provide a firearm which, through its use of a dry chamber enables seals simpler than heretofore employed in liquid propellant type guns. Another object of this invention is to provide a liquid propellant system capable of adaptation upon all firearms regardless of type or size. A further object of this invention is to provide a gun embodying all the features in combination discussed above. And another object of this invention is to provide a liquid propellant type gun capable of being maintained in ready-fire condition for indefinite periods. Other objects will become apparent to those skilled in the art upon reading the following detailed disclosure and drawings in which:

Figure 1 discloses a schematic drawing of the system of this invention showing a cartridge in position to be fired, with the regenerative injection means ready to be activated.

Figure 2 is a schematic drawing showing the system just after the primer of the projectile has been ignited and the regenerative injection means beginning to operate.

Figure 3 is a schematic drawing showing the system as it appears at substantially the end of the metering stroke of the regenerative injection means.

Figure 4 is a broken perspective view of an embodiment of a projectile for use in the system disclosed in Figures 1 to 3.

Figure 5 is a partial side view of an embodiment of a gun utilizing the system disclosed in Figures 1 to 3 and the projectile disclosed in Figure 4.

Figure 6 is a cross sectional view of the gun shown in Figure 5 taken on line BB.

Figure 7 is a cross sectional view of the gun in Figure 5 taken on the line CC.

Figure 8 is a cross sectional view of the gun in Figure 5 taken on line AA.

Figure 9 is a right perspective view showing mostly the receiver and butt-stock structure of the gun of Figure 5.

Figure 10 is a left perspective view of the receiver and adjacent parts of the gun of Figure 5.

Figure 11 is a broken perspective view of the parts shown in Figure 9.

The objects of this invention are accomplished, broadly speaking, by a gun system using an initiating charge which upon being ignited, preliminarily acts upon a metering piston through the force of its gases to cause an injection of liquid propellant into the chamber of the gun. This liquid propellant then is ignited and the force of its gases drives a projectile out the bore of the gun. More particularly speaking, the objects of this invention are accomplished with the use of a gun which at the outset ignites an initiating charge to generate gas, the pressure of which is used to start the action of the gun. The force of the gases preliminarily drives a metering differential area piston which forces liquid propellant by an adjustable piston stroke into the dry chamber of the gun. The liquid propellant is ignited from the flame of the burning initiating charge and, therefore, generates additional gas pressure. This gas pressure not only drives a projectile out the bore of the gun but also drives the metering piston to the end of its stroke. Hence as the projectile travels down the bore of the gun, regenerative injection of the propellant occurs thereby enabling a desirable pressure-time relationship of the projectile travel in the gun. The employment of a dry chamber enables not only simpler seals but also the possibility of maintaining the gun in ready-fire position without fear of leakage or corrosion of the chamber by the liquid propellant. The desirable advantages of pyrotechnic ignition as well as the use of a monopropellant are other features of this invention.

Referring to Figures 1, 2 and 3 which disclose broadly the gun system of this invention, there is shown a bore 1 of a gun. Within the rear section of the bore is a chamber in which is shown a projectile 3 about to be fired. The projectile has a band 4 around its base which covers a primer shown in more detail in Figure 4. The projectile shown is fired by a firing pin 5, which hammers against band 4 of projectile 3 to cause ignition of a percussion sensitive primer, the flash of which ignites an initiating charge within the projectile. It should be noted that other ignition means such as electrical means, separate initiating means within the gun itself and the like may be employed and obviously under such conditions there will be modifications required in the manner of igniting the initiating charge. Leading from the chamber is a gas port 6 which communicates with

one end of a metering chamber 7. Within the metering chamber is contained a differential area piston 8, the larger area 9 of the piston facing the inlet of the gas port 6. The smaller area 10 of the piston 8 is on the opposite side and contacts liquid propellant 11 contained within the metering chamber 7. The smaller area is effected by integrally attaching a guide rod 12 to the liquid propellant face 10 of the piston. This guide rod acts to guide the proper movement of the piston. The liquid propellant is passed into the metering chamber through inlet 13 containing check valve 14 which only permits flow into the chamber. The liquid propellant containing section of the metering chamber communicates with injection port 15. Port 15 communicates with the chamber 2 of the bore 1, and contains a check valve 16 which again only permits flow into the chamber of the bore.

The operation of the projectile propelling system shown in Figures 1, 2 and 3 begins with the loading of projectile 3 into the chamber 2 of the bore 1 and the filling of the metering chamber 7 with the liquid propellant 11. The projectile 3 contains a percussion type primer and an initiating charge. The firing pin 16 is activated to strike the band 4 of the projectile 3 thereby igniting the primer and the initiating charge of said projectile. Gases from the burning initiating charge travel into the chamber 2 and through gas port 6 into cylinder 7. In the cylinder they act upon the metering piston 8 and force the liquid propellant out through injection port 15 into the heretofore dry chamber 2. As the propellant enters into the chamber, it is ignited by the flame and heat of the burning initiating charge of projectile 3. Its ignition causes an increase in the gas pressure of the chamber as well as in the gas port 6 and metering chamber 7. This increase in gas pressure exerts a continuous increasing force against the piston 8 thereby metering the propellant 11 into the chamber 2. Also as the pressure increases and simultaneously with the propellant injection process, the projectile 3 is forced down the bore 1. This illustrates the regenerative injecting action of the system from an initially dry chamber state.

In Figure 4 there is shown an embodiment of a typical projectile for use in a gun such as seen in Figures 5 to 12 which uses the projectile propelling system of this invention. The projectile shown is of standard design having an ogival nose portion 20 and a cylindrical body portion 21. The rear portion of the projectile body has a narrower diameter in order to accommodate a ring or tubular band 4 which covers a percussion type primer 23 contained within a wide but shallow groove 24 encircling the periphery of the body portion 21. The band 4 is fastened to the projectile by crimping its end portions 25 and 26 inwardly into oblique channels 27 and 28 respectively upon the body of the projectile. Tab 29 of the projectile is then crimped inwardly upon the crimped end portion 25 of the band 4. The projectile has an axial cavity 30 in which is contained an initiating charge 31. Radially extending flash ports 32 communicate the axial cavity 30 with the primer groove 24. The rear end of the cavity 30 is sealed with rupturable and consumable disc 33.

The projectile of Figure 4 is fired by percussion of a firing pin against band 4. This ignites the primer 23 and its flash travels down flash ports 32 and contacts initiating charge 31. After ignition of the initiating charge by the primer flash disc 33 is ruptured and consumed. The gases from the burning initiating charge are used to initially operate the propelling system as described above and as will be described more fully below with reference to a gun employing the projectile shown.

With modifications the system of this invention could employ other type shells. For example the caseless projectile disclosed in copending patent application entitled "Ignition System," Serial Number 415,537 filed March 11, 1954, now abandoned, could be used if the shell were adapted to hold an initiating charge for initially activating the metering piston of this system. If desired, one could use cased ammunition in which the case contains the primer and the initiating charge and the projectile is a standard solid slug of metal. Obviously, there are other useful projectiles that would be operative.

Figures 5 through 11 illustrate a particular embodiment of a rifle employing the projectile propelling system of this invention. Obviously, other rifles employing the system could be formulated.

The rifle shown in these figures has a barrel 40 with an axial rifled bore therein. The rear end of the barrel is threaded into a receiver extension 42 which in turn is threaded into a receiver 43. The receiver extension has a chamber 44 into which a projectile 45, similar to that shown in Figure 4, may be inserted. Chamber seal 47 of bolt 46 seals the rear end of the chamber. The chamber seal 47 has seal rings 48. Bolt 46 is capable of reciprocable movement within receiver 43. Bolt operating section 49 of operating rod 50 contains an angular cam slot 51, the surfaces of which act to operate the locking lug 52 of the bolt 46. Rearward movement of the operating rod 50 (see Figures 6 and 9) lifts the locking lug 52 to unlock the bolt. Complete forward movement swings the locking lug 52 down to lock the bolt (see Figures 5 and 11). The rod 50 has a finger piece 53 and is spring biased forwardly by an operating rod spring 54. The spring acts to keep the bolt 46 in battery position through the action of the operating rod 50.

Within a vertically disposed annular cavity 57 in the receiver extension 42 is a firing pin 58 spring loaded upward by a firing pin spring 59 when the pin is cocked. The pin is cocked when its cocking shoulder 60 is engaged by the sear shoulder 61 of trigger 62. A firing pin cocking cam pin 63 extends horizontally outward from firing pin 58. It is engaged by an oblique cam surface 64 on the undersurface of the forward section of the operating rod 50. The firing pin is depressed downward on the rear or cocking stroke of the operating rod. Around the forward surface of the firing pin body is an annular groove 66 which acts as a gas seal. The primer striking portion 67 of the pin 58 is of small diameter. Resting upon the shoulder between the body and the primer striking portion 67 of the firing pin 58 is a washer 68 of resilient material such as rubber, neoprene and the like and a metallic washer 69. (See Figure 6.) These act as the primary seal against leakage downward from the chamber into the firing pin cavity.

The trigger 62 is contained within the receiver extension 42 and is pivoted about trigger pin 70. The finger piece 71 of the trigger extends into a space enclosed by trigger guard 72. A trigger spring 74 normally spring biases the trigger in a counter-clockwise fashion about trigger pin 70. A conventional notched cross bar safety 73 can operate upon the trigger to prevent its movement.

In a forwardly extending horizontal cavity 80 forward of the trigger and firing pin assemblies is a gas metering and injection system. The system consists of the cavity 80 which is the cylinder. Within the cavity is a piston 81 having seal rings 82. Extending forwardly from the piston 81 is a hollow tubular guide rod 83 having propellant port 84. A needle valve 86 disposed between guide rod 83 and metering plunger 87 acts as a flame arrestor and closes off the forward end of the hollow opening of the guide rod until the needle valve is pushed forward past port 106 and the needle valve have seal rings 88 and 89 respectively at their front ends to prevent leakage. Seal ring 88 prevents forward leakage of the liquid propellant into the needle valve cavity. Seal ring 89 prevents forward leakage of the propellant gases that may travel down port 106 and of liquid propellant into the plunger and plunger spring cavity. The plunger 87 which bears against the needle valve member is spring biased rearwardly by a plunger spring 90. The spring and the plunger are normally housed within a plunger housing

91 which is threaded into the receiver extension 42 beneath the barrel 40. The forward end of the plunger housing is plugged by a threaded plunger housing plug 92. A bushing 93 around the neck of plunger 87 acts as a guide upon the stroke of the plunger. Vents 94 and 95 relieve any pressure built up within the plunger housing.

Cavity 80 within the receiver extension is sealed at its rearward opening by a threaded plug 100 (see Figures 5 and 12 especially). The plug has a peripheral groove 101 into which gas port 102 enters. The port directs propellant gases from the chamber 44 into groove 101. After entering into groove 101, the gases are directed against metering piston 81 by plug gas port 103. In order to increase the effectiveness of the gases in moving the piston 81 forward, a pocket 104 may be cupped into the head of the piston. Plug 105 seals the hole that was required to be made for drilling gas port 102.

Needle valve 86 acts as a flame arrestor preventing flame that may travel down port 106 from contacting the propellant charge in the compression chamber 80. Propellant port 106 leads from the needle valve cavity into valve assembly 107 (see Figures 8 and 11 especially). When the needle valve is pushed forward past the opening of the port, the liquid propellant flows upward into the port 106 and into the valve assembly. The valve assembly has a threaded tubular member 108. The tubular member has an annular shoulder 109 within its axially located cavity 110 which acts as a step against ball 111. Ball 111 is detachably secured to a plunger 112 which is spring biased outwardly from the shoulder 109 of the annular cavity by valve spring 113. This spring biasing outwardly seats ball 111 upon the axial opening of the shoulder 109. Plug 114 is threaded into tubular member 108. A peripheral groove 115 around the tubular member 108 with radial ports 116 lead the propellant into the interior of the tubular member. Injection port 117 extends from the ball portion cavity of the tubular member 108 to the chamber 44 of the gun. A seal 118 prevents leakage around the threads.

The metering piston 81 is loaded with liquid propellant through an injection port 125. This port is within a threaded nipple 126. A propellant supply conduit 127 connects the tank 124 with the port 125. At the inner end of the nipple is a counterbored cavity 129 in which is contained a check valve 130 biased by spring 131. Ports 132 and 133 lead into the volume enclosed by the needle valve 86 and metering cavity 80. An air bleed valve 134 vents the volume of the propellant supply conduit 127 and part of the volume of the injection port 125 on the outer side of the check valve 130.

Within the receiver 43 and to the rear of the metering assembly in the receiver extension 42 is a magazine 120 in which caseless projectiles 45 are stored until use. A magazine spring 121 and a magazine follower 122 force the projectiles 121 upwardly in dispensing fashion to the bolt 46. The magazine is held in place by a magazine catch 119.

Within gun stock 123 is contained a tank 124 for storage of liquid propellant (see Figure 9). The propellant within the tank is transferred to the metering assembly of the gun by pressure induced within the tank through operation of a hand operated pressure pump 135. This pressure forces the liquid propellant out through supply conduit 127, into the injection port 125 of the gun and then into the propellant chamber 85 of the metering cavity 80.

To operate the gun of Figures 5 to 12, tank 124 within gun stock 123 is first loaded with liquid propellant. A magazine 120 containing caseless projectiles 118 of the design shown in Figure 4 is inserted into the magazine opening with the receiver 43. Magazine catch 119 holds the magazine in place. Trigger safety is placed in an "on" position. The liquid propellant in tank 124 is next pumped into metering cavity 80 by hand operation of pressure pump 135. The pump builds up pressure within the tank forcing the propellant out through supply conduit 127 through the injection port 125 and into metering cavity 80 shown in Figure 5. The pressure in the tank may be built up to the point that hand pumping will only be required after a series of rounds have been fired—the number of the series depending upon the pressure. Use of the reciprocating actions of the bolt could also be used to maintain the pressure between the injection port 125 and cavity 80, the propellant flows through check valve 130 (see Figure 8) through ports 132 and 133 (see Figure 8) and into the compression chamber of the metering assembly by feed port 78. Feed port 78 leads directly from ports 132 and 133 into the compression chamber. The propellant supply conduit is bled free of air when first firing by air bleed valve 134. Next operating rod 50 is pulled rearwardly. This movement cocks the firing pin 58 by action of cam surface 64 of the rod acting against cocking cam pin 63 to depress the firing pin against spring 59. The sear shoulder 61 of the trigger 62 engages the cocking shoulder 60 of the firing pin when the pin is sufficiently depressed downwardly. Movement of the operating rod also causes unlocking of the bolt 46 by swinging locking lug 52 upwardly through action of angular cam slot 51 of the rod 50, and rearward movement of the bolt. Upon release of the rod 50, operating rod spring 54 causes forward movement of the rod and bolt. A caseless projectile is swept off the top of the stock of caseless projectiles of the magazine and into the chamber 44 of the receiver extension 42. The bolt is locked at the completion of the reload stroke by action of cam slot 51 upon locking lug 52.

The gun is fired by placing the safety 73 in an "off" position and pulling the finger piece 71 of the trigger 62 rearwardly. This causes the sear shoulder 61 of the trigger to release the cocking shoulder 60 of the firing pin. The pin is driven by force of firing pin spring 59 into the band of projectile 45. The percussion type primer 23 under the band 22 is thereby ignited (see Figure 4). The flash from the ignited primer 23 travels through flash holes 32 and onto the initiating charge 31. The initiating charge becomes ignited and in burning generates gas pressure which travels through gas port 102, groove 101 of plug 100, plug gas port 103 and into pocket 104 of the metering piston 81. The metering piston is driven forwardly by these gases against the force of the plunger spring 90. As this occurs, liquid propellant contained in propellant chamber 85 is driven out of said chamber through port 84, through the cavity of guide rod 83, and into the volume rearward of the needle valve 86. When the needle valve 86 is driven forwardly past port 106, the propellant is driven upwardly through propellant port 106, through the valve assembly 107 and then into the chamber 44 of the gun. In the valve assembly 107, the propellant flows around tubular member 108, in groove 115, then into radical ports 116, around plunger 112, against ball 111 and through injection port 117. After entering into the chamber, the propellant burns generating additional gas pressure which is used to continue the injection system just described and to drive the projectile 45 out the bore 41 of the gun. This continuous injection of the propellant as it burns and as the projectile travels is known as regenerative injection. It should be noted that the chamber 44 was initially in a dry state until the burning initiating charge 31 caused injection of propellant into said chamber. By adjustment of the force of spring 90 through plug 92, the metering rate can be controlled for optimum energy usage of the propellant. In use, monopropellants are operable because burning is already present in the chamber when said propellant is used.

Obviously, the projectile propelling system is useful for all caliber weapons. Other designs for the gun and the projectile including the manner of ignition, type of projectile employed, the valve arrangement of the metering

system, the liquid propellant storage system, adaptation to automatic operation and other features not recited are possible and can be made without departing from the spirit and scope of the invention as set forth in the appended claims.

The invention having thus been described what is desired to be secured by Letters Patent is as follows:

1. A liquid propellant gun comprising a receiver, a receiver extension fixed to said receiver and containing a chamber, ignition means, a liquid propellant metering assembly, a barrel fixed to the receiver extension, a reciprocating bolt operable to seal one end of the chamber, a projectile operable to seal the opposite end of the chamber and a liquid propellant supply, said metering assembly including a metering cylinder and a metering piston, one face of the piston cooperating with the cylinder to define a metering cavity, the opposite face of the piston cooperating with the cylinder to define a pressure pocket, conduit means connecting the metering cavity with the chamber and connecting the chamber with the pressure pocket, a one-way valve disposed in the metering cavity conduit means effective to permit fluid flow in circulatory fashion from the metering cavity to the chamber and thence to the pressure pocket whenever the piston is moved in a direction which tends to pressure fluid within the metering cavity.

2. A liquid propellant gun comprising a receiver, a receiver extension fixed to receiver, a projectile and a liquid propellant supply, a barrel fixed to the receiver extension, a bore extending through the barrel and the receiver extension, a bolt cavity formed in the receiver and intersecting the bore, a reciprocating bolt disposed within the bolt cavity and operable to seal one end of the bore, said projectile being effective to seal the opposite end of the bore, said receiver extension containing an ignition means and a liquid propellant metering assembly, said assembly comprising a metering cylinder, a differential area piston disposed in the cylinder and carrying a tubular guide rod, a conduit leading from the bore to one side of the piston, a second conduit leading from the opposite side of the piston through said guide rod to the bore and means for introducing propellant to the opposite side of the piston, said second conduit containing a flow control means.

3. A liquid propellant gun as defined in claim 2 wherein the flow control means comprises an adjustable needle valve.

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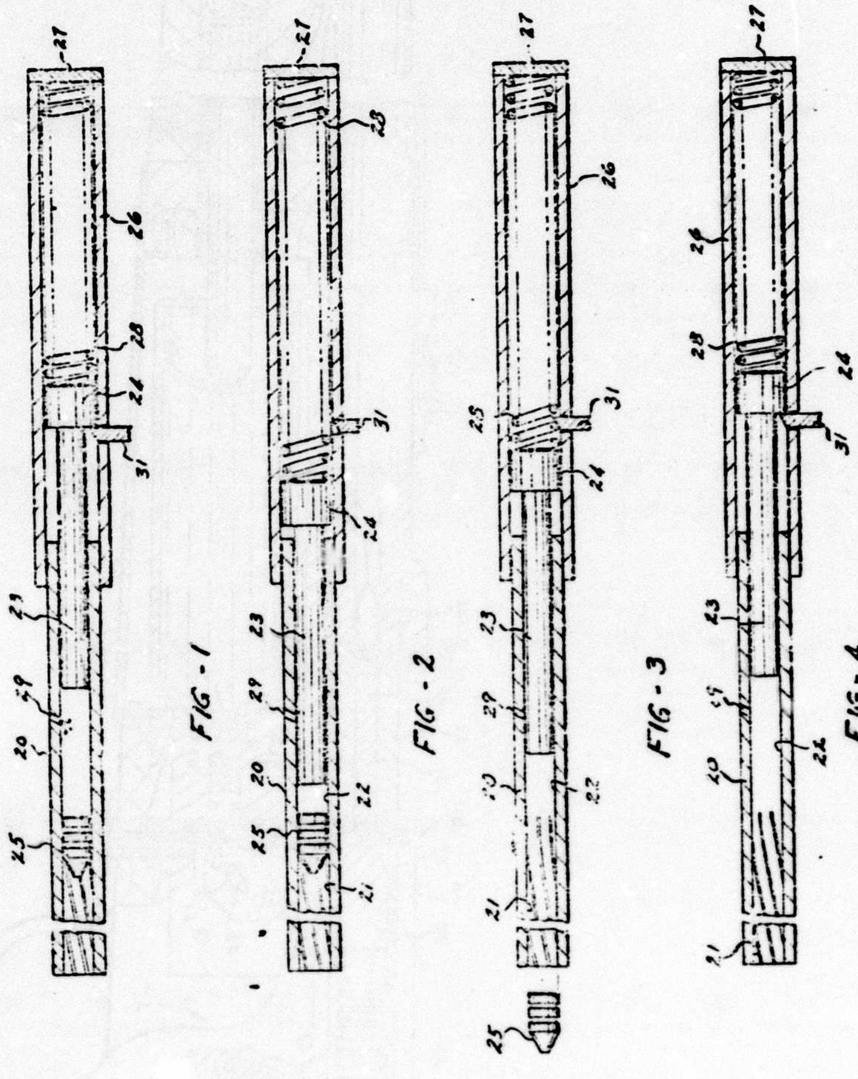
COMPRESSION IGNITION GUN

Filed Dec. 10, 1956 3 Sheets-Sheet 1



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COMPRESSION IGNITION GUN

Filed Dec. 10, 1956 3 Sheets-Sheet 2

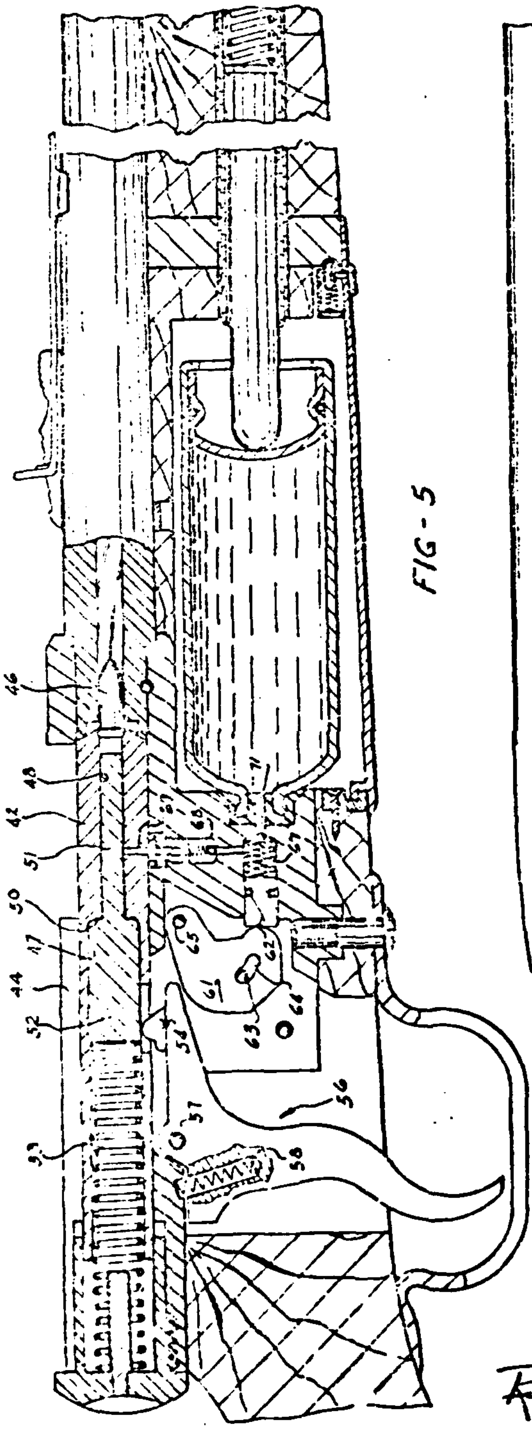

FIG-5

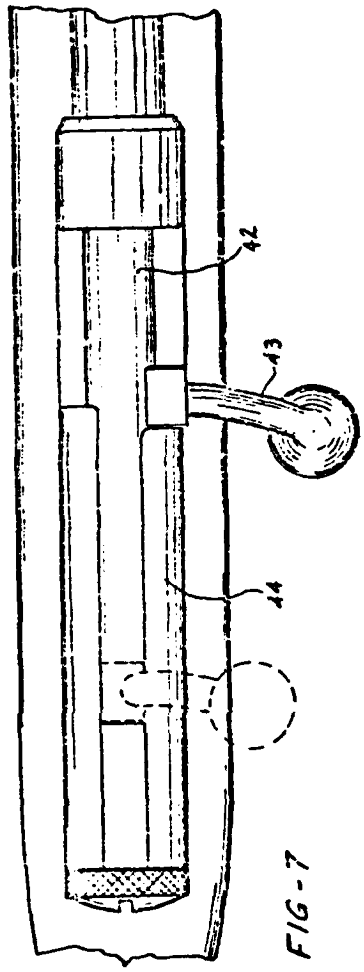

FIG-7

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COMPRESSION IGNITION GUN

Filed Dec. 10, 1956 3 Sheets-Sheet 3

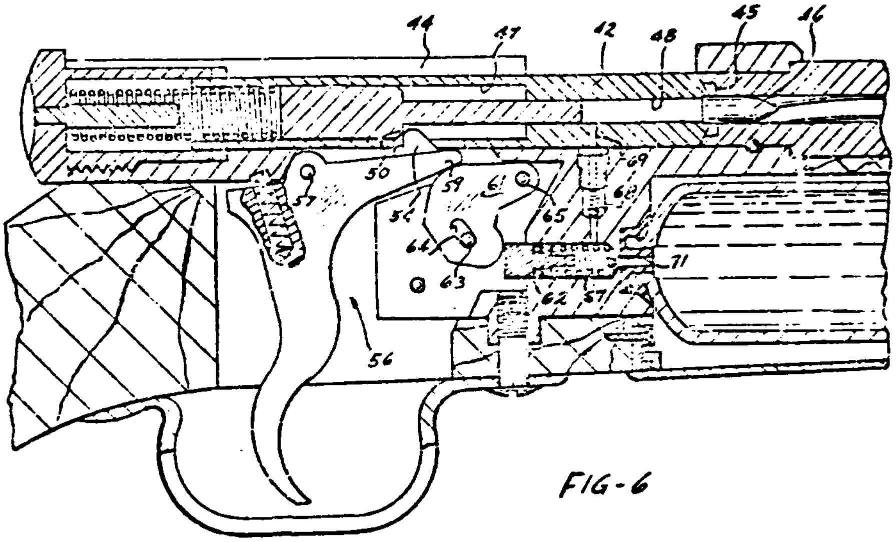

FIG-6

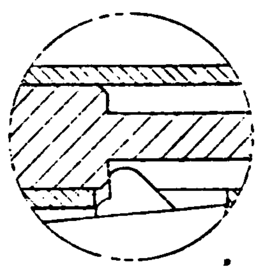

FIG-8

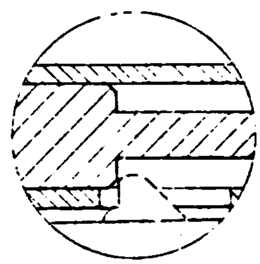

FIG-9

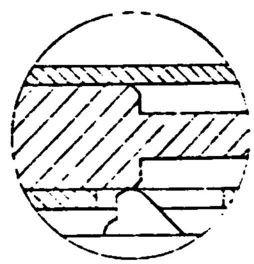

FIG-10

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Patented Aug. 2, 1960

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COMPRESSION IGNITION GUN

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Filed Dec. 10, 1956, Ser. No. 627,724

2 Claims. (Cl. 89—7)

The present invention relates to devices for advancing projectiles and is particularly concerned with projectile advancing devices which utilize fluid monopropellants.

Our invention, in particular, utilizes the phenomenon of vapor compression ignition to ignite and explode a charge of liquid propellant in a firing or compression chamber to propel a projectile from the chamber.

Vapor phase ignition of combustible substances by adiabatic compression is a well-known phenomenon and has heretofore been utilized on a large scale for ignition of air-fuel mixtures in diesel engines and the like. The compression ignition phenomenon has also been found to be undesirable and even hazardous in other circumstances, for example, in the use of liquid monopropellants in various rocket applications where the monopropellant can be subjected to sudden compression when vaporized or partially vaporized during rapid opening or closing of valves in the pumping system.

It is a particular object of the present invention to provide a projectile propulsion mechanism in which the phenomenon of compression ignition is utilized.

It is a further object of the present invention to provide a purely mechanical ignition system for such a mechanism, thus eliminating the need for fixed ammunition, primers, electric sparks or other ignition schemes.

A still further object of the invention is the provision of an automatic weapon of any desired caliber wherein the propellant in liquid form may be contained conveniently in a reservoir attached to or closely associated with the weapon.

Another object of the invention is the provision of a gun in which the projectiles or bullets are handled separately and are thus not associated with a cartridge casing of any kind.

Another object of the invention is the provision of a compression ignition liquid propellant projectile advancing scheme which is readily adaptable to present day powder actuated tools. The tools referred to here are those used to drive rivets, bolts, studs, and other fasteners.

Basically, the propulsion mechanism of the present invention simply requires a main body member of any desired shape formed with a bore defining a cylinder, a barrel having a firing chamber and adapted to receive a projectile therein, said barrel being removably attached to and communicating with the bore of the cylinder, a piston slidably positioned within the bore, projecting into the firing chamber and provided with a mechanism such as a spring for driving the piston forward towards the mouth of the barrel to reduce the volume of the firing chamber.

The mechanism is operated by chambering a bullet, a stud or other projectile at the forward end of the chamber, ramming the projectile home (usually to the beginning of the rifling or other sealing means) and injecting a metered charge of a liquid propellant, susceptible of compression ignition, into the chamber between the piston and the projectile. Thus, the propellant is con-

tained within a cavity of the firing chamber bounded on the forward end by the projectile (which makes a fluid tight seal with the barrel) and rearwardly by the piston.

As will become more apparent hereinafter, the bullet may be inserted by hand through the rear end of the chamber by providing a suitable quick operating disconnector between the barrel and the cylinder or by providing a slidable bolt as in a bolt action firearm.

After the bullet and the liquid propellant are positioned as described above, the piston is driven forward towards the projectile causing the gases or vapor in the chamber to be compressed under approximately adiabatic conditions. The internal heat generated thereby ignites and explodes the propellant, driving the bullet, stud, or other projectile through the barrel and out of the muzzle at high velocity. The reaction of the explosion may be utilized, if desired, to operated upon the piston in the manner of a blow back operated gun to drive the piston rearwardly where it may be latched ready for the next compression stroke.

The gases or vapors which are heated by compression in the chamber may be air, propellant vapor, or the gaseous products of previous combustions of the propellant.

It is to be understood that by the term "propellant" it is intended to designate liquid monopropellants susceptible of compression ignition. Examples of such monopropellants are nitromethane, propyl nitrate, and a mixture containing by weight approximately 60 percent hydrazine approximately 33 percent hydrazine nitrate and about 7 percent water.

It is to be noted that propellants of the above general description have been ignited in .30 caliber guns developing muzzle velocities as high as 1700 feet per second using bullets of standard weight, i.e., 100–150 grains.

Having described the general principles of the present invention, a mechanism embodying the principles will be described. The invention will also be described as adapted to a conventional single shot rifle.

Obviously, the principles of the invention are not limited to firearms but are adaptable to so-called powder actuated tools utilized to drive studs or bolts into building materials. Accordingly, the use of the term "projectile" herein is intended to include bullets, studs, bolts, rivets and the like.

Referring now to Fig. 1, there is shown schematically a sectional view of a firing mechanism constructed in accordance with the principles of the present invention and illustrating to advantage a projectile seated in the firing or compression chamber, the piston in the cocked position and propellant being injected into the firing chamber;

Fig. 2 is a view similar to Fig. 1 and shows the piston advancing toward the projectile to bring about adiabatic compression of the monopropellant;

Fig. 3 is also similar to Fig. 1 and shows the projectile leaving the barrel and the piston at a point along its return path;

Fig. 4 shows the piston fully returned and latched ready for the next firing;

Fig. 5 is an elevational view of a portion of a single shot rifle with which the principles of the invention may be associated and showing the compression piston in the forward position;

Fig. 6 is a view similar to the showing of Fig. 5 illustrating the compression piston in the rear or cocked position;

Fig. 7 is a plan view of a portion of the rifle of Fig. 5 showing the bolt operating arm to advantage;

Fig. 8 is a view of the sear and bolt assembly, somewhat enlarged, in the cocked condition;

Fig. 9 is a view of the same elements in the position which represents the start of the pump stroke; and

Fig. 10 is a view of the elements in the position which represents the end of the pump stroke.

Referring now to Figs. 1 through 4, the reference numeral 20 designates a barrel having a rifled bore 21 terminating in a smooth bore defining a firing chamber 22.

A piston 23 having a head 24 is slidably positioned in the chamber. The rear end of the barrel 20 is received within and removably fastened, by means not shown, to a cylinder or tubular spring case 26. It is intended that the barrel 20 and the cylinder 26 threadedly engage one another, such as by interrupted threads so that the barrel may be readily removed for the purpose of inserting a projectile 25 into the chamber and ramming it home (to the origin of the rifling) to make a fluid tight seal. As shown in the drawings, the cylinder 26 is enclosed by a plate 27 and the piston head 24 is slidable in the cylinder. Disposed between the piston head and the plate is a coil spring 28. The spring is under a substantial compressive load at all times and is used to drive the piston toward the projectile.

The compression or firing chamber 22 is provided with a port 29 through which a metered charge of fluid monopropellant of the type previously described is injected between the piston 23 and the projectile 25 disposed as shown in Fig. 1.

The port 29 must be fitted with a one way check valve which opposes discharge of fluid from the interior of the chamber and any suitable positive displacement pump means may be utilized to meter the liquid through the barrel into the chamber. When the barrel 20 and the cylinder 26 are disconnected for the purpose of inserting a projectile, the piston 23 is pushed rearwardly compressing the spring 28. A latch 31 is provided for latching the head of the piston in the position shown in Fig. 1.

Since ignition of the liquid propellant is accomplished by adiabatic compression, a minimum compression ratio is required to generate sufficient heat to cause ignition. This minimum compression ratio is dependent on the particular propellant used, and also on the ratio of liquid to vapor volume in the chamber. Compression ratio is controlled by the force of the spring, and the mass and cross-sectional area of the piston, and compression ratios as high as 100:1 are sometimes required.

With the piston latched by the element 31 and propellant disposed between the head of the piston and the bullet 25 as shown in Fig. 1, release of the piston will permit it to drive forwardly toward the projectile in response to the urging of the spring 28. A sudden and substantially adiabatic compression of the vapor volume in the chamber occurs, generating sufficient internal heat to bring about ignition.

Upon ignition, the propellant burns explosively and the projectile or bullet is propelled along the barrel and leaves the barrel at high velocity, as shown in Fig. 3, while the piston 23 is driven toward the rear in the manner of a firearm having "blow-back" operation. The blow-back action of the piston occurs at a relatively low velocity because of its high mass (relative to the mass of the projectile) and the head of the piston overrides the latch 31 and is latched in the position shown in Fig. 4.

Referring now to Figs. 5 through 10 and in particular to Figs. 5, 6, and 7, there is shown a shoulder firearm with which the principles of the present invention may be utilized. A bolt action rifle designated generally by the reference number 41 is provided with a bolt 42 having an operating handle 43. The bolt is slidable to and fro in a slide 44.

Obviously, the bolt may be moved from a forward position as shown in Fig. 7 to a rear or open position as represented by the dotted lines in Fig. 7. In the open position, projectiles such as a bullet 46 may be readily inserted into the barrel as at 45. The bolt is provided with a first bore 47 which communicates with a second bore 48 hereinafter referred to as a compression or firing chamber. A piston 51 having a head 52 is slidable within the bolt. A coil spring 53 is operable to urge the piston to the right as viewed in Fig. 5.

The bolt 42 is of the rotating-lock type and as is apparent in Fig. 7 is operable to be rotated until the operating handle 43 is in alignment with the slide 44 and may thereafter be moved to and fro along the longitudinal axis of the gun.

Upon moving the bolt to the left, as viewed in Fig. 5, the piston 51 is carried to the left until a shoulder 50 formed on the piston overruns a sear 54. The sear is integral with a trigger assembly indicated generally by the reference numeral 56, pivotally mounted in a receiver by a pin 57. A spring 58 constantly urges the trigger assembly in a counterclockwise direction so that whenever the piston is moved to the left, a distance sufficient to permit the shoulder 50 to override the sear, the piston is held in a cocked position as shown in Fig. 6. An arm 59 formed integral with the trigger assembly rides upon and actuates a pump cam 61 which in turn bears upon a pump piston 62. The pump cam 61 is rotatable about a pin 65 through an arc limited by the slot 64 and the follower 63.

In the manner which will become more apparent hereinafter the pump cam is operable by manipulation of the trigger to move from the position shown in Fig. 6 to the position of Fig. 5. During the course of this cam rotation, the pump piston 62 is moved to the right (Fig. 5) against a spring 67 to pump a metered quantity of fluid past a check valve 68 into the chamber 48 by way of a conduit 69. It is to be noted that pump cavity is also provided with a check valve 71 to seal the cavity during the pumping action.

Referring further to Fig. 5, there is shown a liquid propellant container 72 having a relatively movable bottom 73. The bottom is engaged by a push 74 which is in turn urged to the left by an actuating spring 76. The actuating spring is constantly under compression so that a force is exerted at all times on the push rod which in turn tends to urge the movable bottom 73 to the left thereby pressurizing propellant within the container.

The fluid pressure under which the propellant is maintained is selected so as to be slightly in excess of the spring pressure exerted by the pump check valve 71. In this way, there is always the assurance of transfer of liquid propellant from the container 68 to the pump cavity 66 when the pump piston assumes the position shown in Fig. 6.

It is to be noted that the spring pressure of the check valve 68 must be of sufficient strength to preclude admitting liquid propellant into the chamber prematurely, i.e., prior to the pumping stroke. In other words, the spring pressure of check valve 68 should be in excess of that of check valve 71.

Attention is directed to the fact that operation of the pump cam and pump piston must occur prior to the passage of the compression piston by the inlet conduit 69. This is accomplished by providing sufficient height to the sear 54 so that there may be appreciable rotation of the trigger and corresponding rotation of the pump cam without unlatching the compression piston.

This action is more apparent from the showing of Figs. 8, 9 and 10 wherein Fig. 8 shows the compression piston fully latched and the trigger and the pump actuating cam in the initial position. The position of these elements at this time corresponds to the showing of Fig. 6.

In Fig. 9 there is a showing of the relationship between the sear and the compression piston during actuation of the pump cam but prior to release of the piston. The relative position of the sear and the piston shoulder illustrated in Fig. 9 indicates that the trigger has been partially rotated in a clockwise direction and the pump cam has been rotated correspondingly in a counterclockwise direction.

Fig. 10 shows the condition of the respective elements just at the instant of release of the compression piston and upon completion of the pump cam rotation.

It is to be understood that when the trigger assembly and the pump cam reach the position indicated by the showing of Fig. 10, the chamber 48 has received a predetermined charge of fluid propellant. Further travel of the compression piston adiabatically compresses the vapor or gas volume in the chamber generating sufficient heat to cause ignition of the propellant. Thereafter, rapid burning occurs and the expansion of the gaseous products of combustion drives the projectile along the rifling and out of the barrel into the atmosphere.

Operation

The operation of the firearm illustrated in Figs. 5 through 10 occurs in the following manner:

Assume that the bolt has been opened in the conventional manner and that a bullet in the form of a lead slug has been inserted into the barrel and rammed to the base of the rifling as shown in Fig. 6. Upon closing and locking the bolt, the compression chamber is sealed, the seal being represented at one end by the projectile seated against the rifling and at the other end by the compression piston. Assume further that the compression piston is in the cocked position as shown in Fig. 6 having been so disposed by opening the bolt or by the "blow back" action of a previous explosion. Since the trigger and sear have been overridden by the bolt and the compression piston, the pump cam will be in the position shown in Fig. 6. Correspondingly, the pump piston 62 will be disposed to the left as viewed in Fig. 6 and the propellant under fluid pressure within the container 72 will have forced propellant into the pump cavity. Since the check valve in the conduit leading to the compression chamber dominates the pump check valve, a charge of propellant will be confined in the pump cavity.

Upon manipulation of the trigger in the conventional manner, the sear gradually draws away from the pump piston shoulder 50 and in the first predetermined arc of rotation of the trigger, the pump cam will be actuated to drive the pump piston to the right (Fig. 6) with a force sufficient to generate pressure which overcomes the check valve 68 permitting the charge of propellant to flow into the compression chamber.

Incidentally, attention is directed to the fact that the motivating power for actuating the pump piston need not be derived entirely from manual operation of the trigger. It is to be noted that the compression spring 53 is constantly urging the compression piston to the right. By virtue of the camming action between the shoulder 50 and the sear 54, the spring 53 helps to drive the trigger through its initial arc of rotation.

Continued rotation of the trigger frees the compression piston to move to the right sealing off the inlet port 69 and compressing the charge of propellant to the relatively small volume such as shown in Fig. 5.

The compression ratio of the compression chamber is selected consistent with the characteristics of the particular liquid propellant, and with the ratio of the liquid charge volume to the total chamber volume. As stated before, sufficient heat is generated during compression to cause the liquid propellant to ignite and burn with an explosive force to propel the projectile out of the barrel of the firearm.

Subsequent operation of the firearm may be accomplished by repeating the steps just described.

It is to be understood that it is entirely within the scope of the present invention that the principles thereof be utilized to actuate tools for advancing rivets, nails, bolts, etc. into building materials as well to advancing projectiles from firearms.

It is also within the contemplation of the invention that the principles thereof be utilized in automatic firearms in which the "blow back" action of the compression piston compresses the operating spring to store sufficient mechanical energy to accomplish feeding of projectiles and other necessary mechanical functions.

It is further contemplated that the principles of this invention can be utilized in various automatic or semiautomatic firearms in which conventional "recoil-operation" or "gas-operation" is utilized in conjunction with the "blow-back" action of the compression piston to accomplish necessary mechanical functions.

What is claimed is:

1. In a firearm including a barrel and a trigger, a bolt operative to engage and make a fluid tight seal with respect to one end of the barrel, said bolt cooperating with a projectile disposed in the barrel to define a compression chamber, a fluid supply container communicating with the compression chamber, pump means in circuit with the container and the chamber and including a piston and a cam operatively connected to the trigger, said pump means being responsive to operation of the trigger effective to meter fluid from the container to the chamber, and compression means including the bolt responsive to operation of the trigger for changing the volume of the chamber whereby fluid introduced therein is pressurized.

2. The firearm of claim 1 wherein the pump and at least two check valves are disposed between the fluid supply container and the pressure chamber, one check valve cooperating with the fluid supply container and the other check valve cooperating with the pressure chamber.

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July 20, 1965 C. F. TURNER 3,195,407

LIQUID PROPELLANT PROJECTILE UNIT

Original Filed May 7, 1963 2 Sheets-Sheet 1

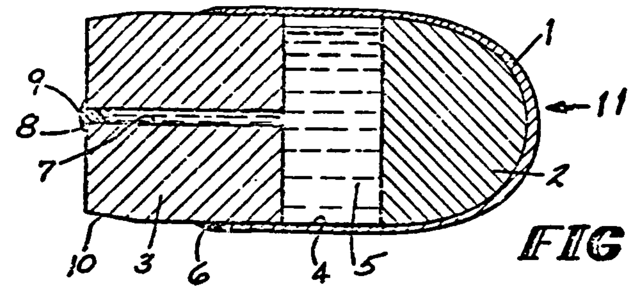

FIG-1

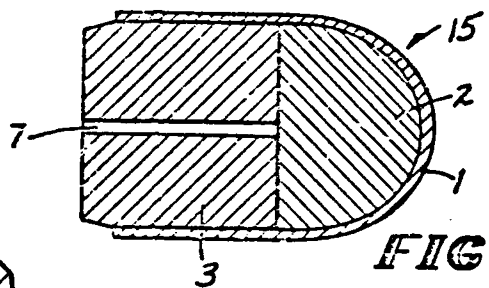

FIG-2

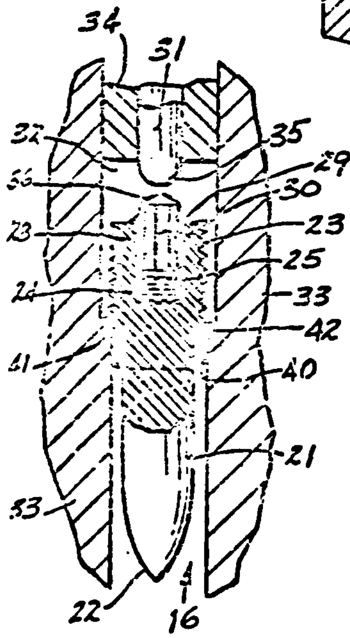

FIG-3

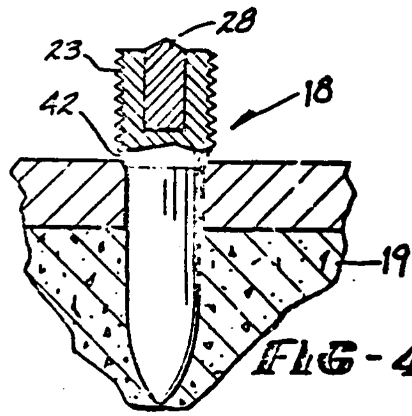

FIG-4

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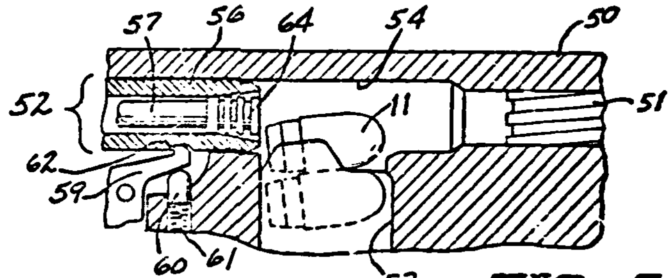

FIG - 5

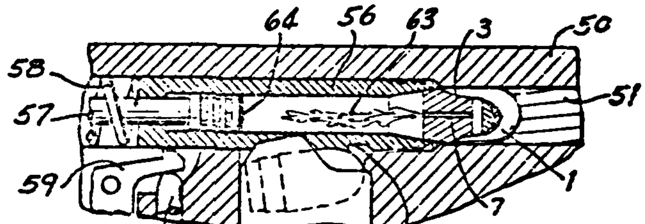

FIG - 6

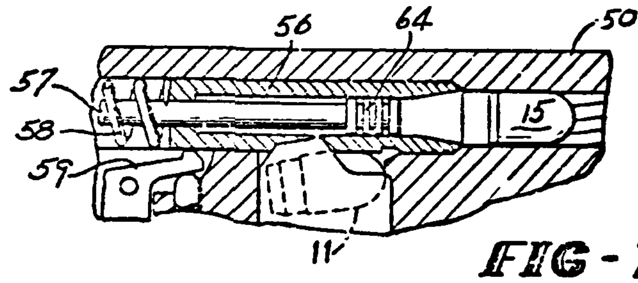

FIG - 7

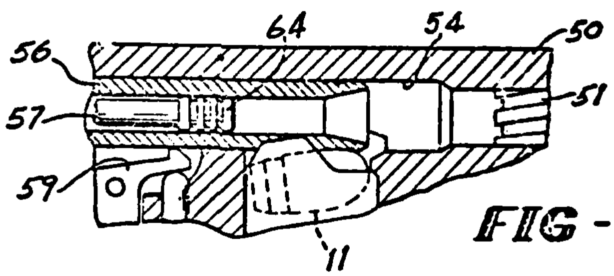

FIG - 8

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3,195,407
LIQUID PROPELLANT PROJECTILE UNIT

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Original application May 7, 1963, Ser. No. 278,676. Divided and this application Oct. 19, 1964, Ser. No. 411,663
3 Claims. (Cl. 89—7)

This application is a division of co-pending application, Serial Number 278,676, filed May 7, 1963.

This invention relates to an explosive driven unit and in particular to bullets and projectile-type fasteners each of which includes and uses a liquid propellant charge.

One object of this invention is to provide a relatively simple primerless type of bullet or projectile fastener which depends on adiabatic compression of gas in the compression chamber of a gun or tool barrel for ignition and explosive expansion of the propellant and thereby avoids need for carrying a propellant charge together with a priming mix separately from the bullet or other projectile unit.

Another object is to provide a simple projectile structure including a charge of mixed liquid alkyl nitrates, a pump piston, and a rupturable seal, all as an integral part of a projectile unit.

Another object is to provide a projectile structure having initially a cavity substantially filled with propellant, thereby avoiding need for additional cavity space for an adiabatically compressible gaseous phase for ignition of the propellant, but having finally a maximum projectable solid body of the desired caliber for projection through a barrel.

Another is a bullet or fastener with a liquid propellant charge, avoiding need for cartridge cases, their extraction or ejection, and also storage and metering devices.

Still another object is the provision of a bullet or fastener providing an accurate propellant charge together with a means for injecting that charge into the compression and firing chamber of a firearm or tool.

Still another object is the provision of a simple but rugged firing apparatus. The apparatus is capable of injecting the charge of liquid propellant in a compression chamber and of applying compression for ignition without the need for a propellant reservoir, for various fluid metering and valving parts, and for an apparatus pumper acting directly on the propellant with attendant deterioration.

Other objects and advantages will be evident from a description of various embodiments shown in the accompanying drawings in which:

FIG. 1 is a longitudinal view in cross section of a bullet according to this invention shown before firing;

FIG. 2 is a longitudinal view also in cross section of the same bullet shown after firing;

FIG. 3 is a longitudinal partly cross sectional view of a projectile type of fastener according to another embodiment of this invention shown before explosive driving in suitable driving apparatus only part of which is shown:

FIG. 4 is a view of the same fastener shown after it has been driven;

FIG. 5 is a fragmentary view of a suitable firing or driving apparatus according to this invention showing the parts and a bullet of the type shown in FIGURE 1 in the ready-to-fire position;

FIG. 6 shows the apparatus and bullet in chambering and pumping position;

FIG. 7 shows the apparatus and bullet during ignition; and

FIG. 8 shows the apparatus with certain of its parts being blown back by the burning propellant gases following ignition to put these parts into the ready-to-fire position again.

As shown in FIGURE 1 there is provided an embryonic bullet 11 consisting of the usual jacket 1 of a suitable copper base alloy, a solid front core section 2 usually of lead or an alloy of lead, and a rear core section 3 fitted snugly in the jacket and displaced rearwardly from the front section to provide a cavity 4 containing a charge 5 of a liquid monopropellant.

For example, in a typical 0.45 caliber bullet, a cavity volume and charge of about 0.5 of a cubic centimeter are contemplated; which is to say that the cavity is to be almost completely filled with an alkyl nitrate propellant, except for a few percent of volumetric capacity left to take up for thermal expansion and contraction of the liquid. A suitable liquid propellant is a mixture of ethyl nitrate and normal propyl nitrate. Specifically, 60 mole percent of ethyl nitrate admixed in normal propyl nitrate, and known as 60:40 EPN, was found to have the desired sensitivity and reliability from the standpoint of adiabatic compressive ignition and stability.

Projecting from the jacket and sealed in by the ring 6 of sealant such as solder or epoxy resin, the rear core section 3 has a central aperture 7 forming an ejection passage hermetically closed by a plug 8 of suitable consumable material such as polyethylene force-fitted into this tiny aperture to prevent loss of propellant before use. The closure 8, which may be further sealed and retained by the application of an epoxy adhesive 9 is adapted to rupture whenever the rear core section 3 is rammed forward by a thrust applied to the trailing end of the section at bevel 10 provided for the purpose.

After firing the projectile assumes the final form of the bullet 15 shown in FIGURE 2 where the sections 2 and 3 are put into abutment inside the jacket to provide a substantially solid bullet characterized by desirable external ballistic parameters.

Firing abolishes the cavity 3 and except for the presence of the remaining central aperture 7 the projected bullet 15 is quite conventional in appearance and behavior as compared to the embryonic forms 11.

The core sections may be of any suitable material such as steel, or a combination of materials to provide desired weight and/or hardness, balance, armour piercing properties, or mushrooming properties.

In FIGURE 3, the embryonic unit 16 is of a form suitable for assuming the final finished shape of the fastener 18 shown in FIGURE 4 driven into a supporting plate 19.

This unit has a main fastener section 21 of steel of suitable hardness and toughness having an ogivally tapered piercing point 22 and a threaded or otherwise formed and enlarged rear end 23, usually as shown to adapt section 21 for attachment of objects to the support. One end of the main section is recessed at the rear to form the propellant cavity 24 containing the EPN mixture 25 and partially containing the compression plug section 28 closing the cavity and retained in hollow section 21 frictionally and/or adhesively with the aid of a sealing ring of epoxy resin adhesive 29. In lieu of central passages, the plug section is provided with longitudinal serrations 30 forming passages around its cylindrical surface for ejection of the propellant when the seal 29 is ruptured as the plug section 28 is pushed in by ram 31 to fill the cavity 24 and drive the propellant out into the compression chamber 32 formed in tool barrel 33 around the ram between the fastener unit 16 and a compression plunger 34 coaxially mounted to slide forwardly with respect to ram 31 after the latter has completed its forward thrust against the fastener plug section.

Ram 31 and section 28 have convex faces 35 and 36, respectively, in juxtaposition to allow for application of the

pressure of the ignited propellant against both sections of the fastener and avoid separation of them.

The serrations 30 take the form of preferably two or three slots equally spaced about the circumference of section 28.

To chamber the projectile fastener unit 16 in the barrel 33 with a desired seal and a desired initial resistance and thereby provide confinement at the front end of the compression chamber there is a tapered shot-start collar 40 forwardly converging to fit between the tapered tool shoulder 41 leading from the chamber to the barrel and the tapered fastener shoulder 42. The collar is made of a suitable plastically deformable metallic or plastic material such as soft aluminum, 50:50 lead-tin alloy or a readily consumable polyolefin such as polyethylene. Alternately, the collar may be formed integrally as a thin readily deformable fin circumferentially extending out between the threads and the tapered shoulder. This, like the malleable metal and the combustible polyethylene, has the advantage of leaving no residual ring in the gun or tool barrel after firing.

In the gun device of FIGURES 5 to 8, shot start and sealing in barrel 50 is provided by ramming the projectile unit home to the beginning of the rifling 51 by means of the compound rifle bolt 52 part of which has a short stroke for picking the unit out of a magazine 53 and positioning it in gun chamber 54. The bolt, as in the driving device shown in FIGURE 3, has two coaxial parts, namely a bolt ram 56 sleeved about an inner propellant compression piston 57. These correspond, respectively, to ram 31 and plunger 34, FIGURE 3. The ram 56 is biased forwardly by the bolt coil spring 58 and is driven forwardly when the bolt sear 59, which is biased by sear follower 60 and its spring 61 into engagement with sear notch 62, is disengaged from the notch in response to the operation of the trigger (not shown). The driven ram then engages at bevel 10 with the piston section 3 of the bullet unit and rams the bullet jacket home while sealing off the gun chamber 54 from the magazine 53 by a sleeve valve action as shown in FIGURE 6. At this stage, there is formed a compression chamber 63 in the tubular ram between the bullet and the head 64 of the compression piston. Continued forward motion of the ram drives section 3 of the bullet forward to break seals at 6 and 9, and unseat plug 8 so that the rammed section 3 may act as a piston directly acting on the liquid propellant to get it through aperture 7 into chamber 63 as shown in FIGURE 6.

Further trigger action releases compression piston 77 to act on the mixture of liquid and gas for adiabatic compression of the latter and ignition of the former as shown in FIGURE 7.

This system allowing a closed breech is admirably suited to automatic recocking by "blow-back" action of the propelling gases acting on both the ram and the piston of the bolt after firing.

Entry of dirt is avoided since the system is closed and requires no outside ports continuously opening and closing with each shot for ejection such as occurs in systems using a cartridge case.

It will be understood that the bullet of FIGURES 1 and 2 need not be jacketed and that the front core section may be integral with the jacket shown. The bullet rear section may take either the centrally apertured form or the form of the uniformly serrated plug section of FIGURES 3 and 4. Likewise, these serrations providing passages at the outer surface of the plug may be replaced by a central passage for ejection of the propellant.

The means for sealing the ejection aperture is adherent to one of the unit sections and is rupturable at a predetermined ram force to release the propellant for adiabatic ignition.

In any event, the recess in the body section and also the plug section both are of complementary cylindrical configuration to adapt these for frictional retention yieldable under a forward thrust to allow telescoping action between the sections for decrease of the cavity volume and ejection of the propellant charge forcefully through the ejection passage for relatively instantaneous fueling of the compression and combustion chamber.

As a safety feature, the cavities 4 and 24 are nearly completely filled with liquid, leaving insufficient volume unfilled for premature adiabatic ignition, in contrast with the compression chamber in the firing device where liquid propellant loading is from about 15 percent to about 45 percent of the initial volume. The liquid ejection ram of the bolt preferably has a somewhat slower stroke than the adiabatic firing compression piston.

What is claimed is:

1. A firing device for explosively projecting units of the type described comprising a barrel, an axially extending bolt operative to engage and make a fluid-tight seal with respect to one end of said barrel, said bolt cooperating with a projectile unit disposed in a position in the barrel opposite said bolt to define a barrel chamber, a first piston means including said bolt for feeding and compressing said unit in said barrel to said position and to eject liquid propellant from said unit into an axially extending compression chamber including said bolt, said compression chamber being formed in said barrel chamber, and a second piston means including said bolt coaxially mounted with respect to said first piston means and having relative axial movement with respect to said first piston means for reducing the volume of said compression chamber whereby the liquid introduced therein is pressurized together with a gaseous phase for adiabatic ignition.

2. The firing device of claim 1 wherein the first piston means is coaxially mounted about said second piston means and is adapted to act on a protruding moveable rear end part of a projectile unit.

3. The firing device of claim 1 wherein the first piston means is coaxially mounted within said second piston means and is adapted to act on a protruding moveable rear end part of a projectile unit.

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BENJAMIN A. BORCHELT, *Primary Examiner.*

Aug. 24, 1965 D. F. BUTLER ETAL 3,202,055

VALVE SYSTEM FOR COMPRESSION IGNITION DEVICE

Filed Nov. 1, 1963

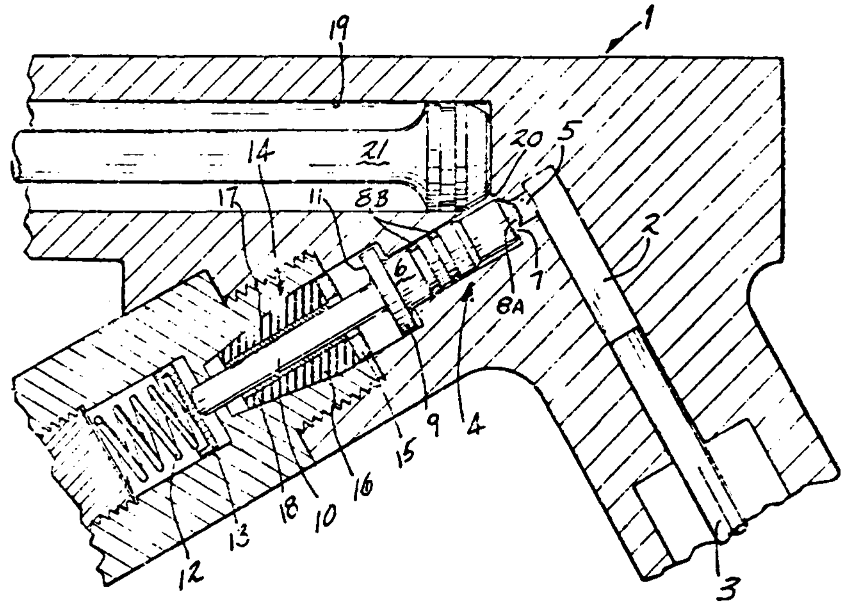

FIG - 1

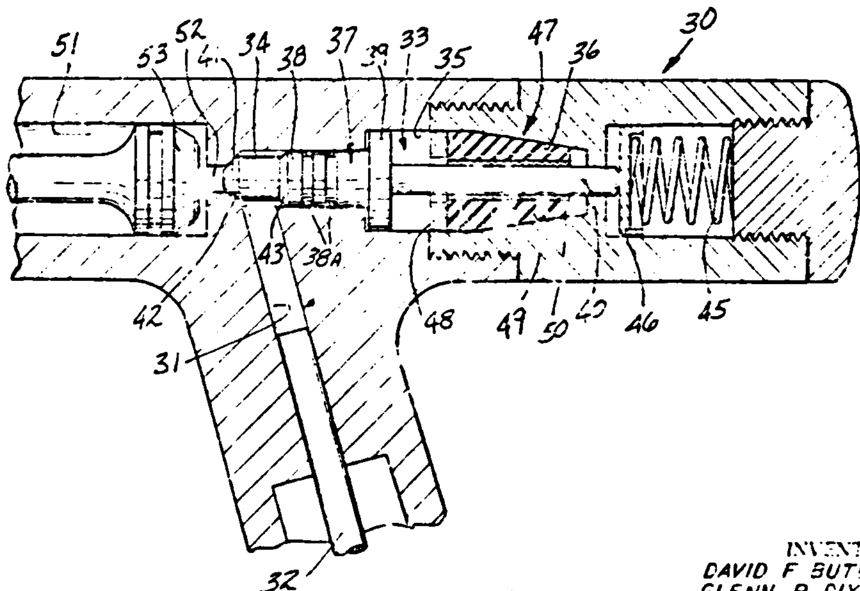

FIG - 2

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United States Patent Office

3,202,055

Patented Aug. 24, 1965

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3,202,055

VALVE SYSTEM FOR COMPRESSION IGNITION DEVICE

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Filed Nov. 1, 1963, Ser. No. 320,904
5 Claims. (Cl. 89—7)

This invention relates to valve systems suitable for use in firearms and tools powered by adiabatic compression of a liquid propellant.

It is known that certain liquid propellants can be compressed into a very small volume and caused to ignite. The compression ignition of the propellant produces high pressure gases which, if properly controlled, can be directed against a projectile or a working piston to act as the propelling force for the projectile or bullet.

One of the basic essentials of a successful liquid propellant system is a valve system which will confine the propellant so that a high enough pressure can be obtained to propagate ignition. The valve must remain closed long enough after ignition to allow for the required pressure buildup and then open for a long enough interval to allow the gas pressure to be transferred from the combustion chamber to a projectile or working piston.

It is therefore a feature of this invention to provide a novel valve system for a liquid propelled firearm or tool.

It is a further feature of this invention to provide a valve system for a liquid propelled firearm or tool which is simple in design, durable, and economical to manufacture.

It is a further feature of this invention to provide a valve system for a liquid propelled firearm or tool which is capable of delivering gases at a predetermined pressure to a work performing element consistently.

It is a further feature of this invention to provide a valve system for a liquid propelled device which will provide an effective seal during the compression stroke while the propellant is compressed to ignition; will continue to seal against gas leakage until a predetermined pressure is attained; and will then quickly open within a fraction of a second and remain open until all the pressure has been exerted against a projectile or working piston.

These and other features and advantages of this invention will become more readily apparent from the following detailed description and drawings in which:

FIGURE 1 is a cut-away sectional view showing one embodiment of this valve system.

FIGURE 2 is a modified form of the invention shown in FIGURE 1.

Referring now to FIGURE 1 of the drawings, a housing generally indicated 1 is provided. Formed or otherwise provided in housing 1 is a combustion chamber 2. 2. A compression piston 3 is slidably mounted in combustion chamber 2 and is moved by means (not shown) toward one end by combustion chamber 2. Piston 3 compresses a liquid propellant which has been injected into combustion chamber 2 by pump means (not shown). The liquid propellant is compressed into a very small volume at a pressure sufficient to cause compression ignition, and combustion of the propellant. A valve chamber 4 communicates with combustion chamber 3 through a reduced opening 5. A valve 6 is mounted for sliding movement in valve chamber 4. The forward end of valve chamber 4 is beveled to provide a valve seat 7 for the conical nose 8A of valve 6. The valve 6 comprises a forward end 8 which includes conical nose 8A, an intermediate guide portion 9 of enlarged diameter, and a rearwardly extending stem portion 10 of reduced diameter. Sealing means such as O-rings 83 prevent gases from bypassing the forward end of valve 6. A shoulder 11 is formed between intermediate guide portion 9 and stem 10. Valve 6 is urged onto valve seat 7 by spring 12 acting through a spring retainer 13 which pushes on the end of the valve stem 10. Snubber means 14 is mounted in the valve chamber 4 to buffer and limit the rearward movement of valve 6 and to retain the valve 6 in its rearward position for a predetermined interval of time. The snubber means may comprise a steel disc 15 and a resilient plug 16. The resilient plug 16 is mounted in a tapered portion 17 of the valve chamber 4 and surrounds valve stem 10. A metallic liner 18 may be fitted on the inside of the resilient plug to improve its wearing characteristics. As the valve 6 moves rearwardly, the shoulder 11 of the valve engages steel disc 15 and causes the resilient plug to be compressed into the conical portion 17 of valve chamber 4. This causes the resilient plug 16 to be compressed and tightly grip valve stem 10. A barrel chamber 19 has one end 20 communicating with valve chamber 4 so that hot gases are transferred directly from the combustion chamber to the barrel chamber as soon as valve 6 is opened. A working piston 21 is slidably mounted in barrel chamber 19 and is moved forward in the barrel chamber 19 by the gas pressure caused by the combustion of the liquid propellant to perform useful work. Instead of piston 21, a projectile such as a bullet (not shown) may be positioned in the barrel chamber and accelerated by the hot gases of combustion.

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The operation of the above described device will now be described.

A suitable liquid propellant is injected into the upper end of combustion chamber 2 by pump means (not shown). The compression piston 3 is moved toward the upper end of combustion chamber 2 to compress the liquid propellant into a very small volume on the order of .030 cubic inch. As soon as a pressure level on the order of 400 p.s.i. is directed against the liquid propellant by means of piston 3, ignition occurs and the pressure in combustion chamber 2 rises rapidly to a range of about 50,000 p.s.i. This pressure acts directly on the tapered end 8 of valve 6 through reduced opening 5. The pressure causes valve 6 to move off valve seat 7 which immediately exposes the entire area at the end of valve 6 to the pressure thus accelerating its rearward motion against spring 12.

The valve 6 is moved rearwardly with an acceleration on the order of 2.5 million ft./sec.². Within a quarter of an inch of travel, the valve builds up an energy level of about 200 ft./lbs. which must be controlled by suitable snubber means if the valve is to function repeatedly over a large number of cycles. To control the valve, a snubber means 14 is provided which may comprise a metal disc 15 of steel or other suitable material and a resilient plug 16 which surrounds the stem 10 of piston 6. As valve 6 moves rearwardly against spring 12, shoulder 11 engages metal disc 15 and moves disc 15 rearwardly against resilient plug 16. The resilient plug 16 is compressed into the tapered portion 17 of the valve chamber and moves radially inwardly about valve stem 10 to grip and retain the valve long enough for the hot gases of combustion to pass into barrel chamber 19 and act on the working piston 21 positioned therein. The self-snubbing feature of snubber means 14 is an important function of my device. Should the valve 6 merely strike a solid surface, it would tend to rebound from the solid surface and close almost immediately, closing off the flow of high pressure gas to the working piston. The trapped gas would then expand its energy against compression piston 3 causing destructive forces in the system. With the snubber means, the valve 6 is gripped and retained long enough (.005 to .010 second) before the valve can return to a fully closed posi-

tion to insure that the high pressure gas gives up its energy to the working piston 21.

FIGURE 2 shows another embodiment of the invention.

Referring now to FIGURE 2, a housing generally indicated 30 is provided. A combustion chamber 31 is provided in housing 30. A compression piston 32 is slidably mounted in combustion chamber 31 and is moved by means (not shown) to compress to ignite a liquid propellant which has been injected into the upper portion of combustion chamber 31 by pump means (not shown). The upper end of combustion chamber 31 communicates with a valve chamber 33. Valve chamber 33 includes a forward portion 34 of reduced diameter, an intermediate portion 35 and a rearward tapered portion 36. Mounted in the valve chamber 33 is a valve 37. The valve 37 includes a nose portion 38, an enlarged guide portion 39, and a stem portion 40. The nose portion 38 of the valve is tapered at 41 and is normally engaged against valve seat 42 formed in the forward end of valve chamber 33 to provide an effective gas seal. A shoulder 43 is formed on the nose portion 38 between the taper 41 and the enlarged guide portion 39. Gas pressure created by the combustion of the liquid propellant acts against shoulder 43 and moves the valve 37 rearwardly against a spring 45 and a spring retainer 46 which normally urge valve 37 against valve seat 42. As soon as valve 37 begins its rearward movement and moves away from valve seat 42, the entire area at the forward end of the valve is exposed to the gas pressure. This causes valve 37 to be accelerated rearwardly so that guide portion 39 engages snubber means 47. Snubber means 47 includes a disc 48 and a split resilient sleeve 49 which surrounds the valve stem 40. A major portion of split resilient sleeve 47 is positioned in the tapered portion 36 of valve chamber 33. A split metallic liner 50 may be provided between stem 40 and sleeve 47 to reduce the effects of wear on the resilient sleeve. Buffer means 45 functions to buffer and snub valve 36 in the same way as described with reference to the embodiment of FIGURE 1.

A plurality of sealing rings 38A are provided to prevent gases from leaking past the nose portion 38 of the valve.

A barrel chamber 51 has one end communicating with valve chamber 33 through reduced opening 52. A working piston 53 or a projectile such as a bullet (not shown) may be chambered in the barrel and accelerated by the hot gases of combustion when valve 37 is opened.

The principal advantage of the FIGURE 2 embodiment resides in the in-line arrangement of the valve and the barrel chamber. Such an arrangement is more suitable for use in a weapon or tool having the conventional appearance of a firearm. In the FIGURE 2 embodiment, the hot gases under pressure act on shoulder 43 to initiate movement of the valve. In the FIGURE 1 embodiment, the gases act directly on the end of the valve. It is therefore apparent that in the FIGURE 2 embodiment, the problem of initially sealing the valve is somewhat more difficult since there is a problem of sealing the valve at the valve seat 42 and around shoulder 43. In the FIGURE 1 embodiment, gas pressure acts initially only against the valve seat 7 and this is the only area where a perfect seal is required.

Other than the differences noted above, the operation of the FIGURE 2 device is identical to the operation of the FIGURE 1 device which has been described in detail above.

While this invention has been described in detail with reference to certain preferred embodiments, variations in design and mechanical modifications are contemplated which are within the spirit and scope of the appended claims.

What is claimed is:

1. In a device actuated by the adiabatic compression and ignition of a liquid propellant include a combustion chamber, a barrel chamber, a valve chamber communicating said combustion chamber with said barrel chamber, a compression piston slidably mounted in said combustion chamber, a valve seat formed between said valve chamber and said barrel chamber, a valve slidably mounted in said valve chamber, said valve having a conical nose portion normally positioned against said valve seat sealing said barrel chamber from communication with said combustion chamber, spring means normally urging said nose portion of said valve into sealing engagement with said valve seat, a rearwardly extending stem formed integral with said valve, and snubber means mounted in said valve chamber surrounding said stem operative to buffer rearward movement of said valve and to retain said valve in an open position for a predetermined interval of time.

2. The device of claim 1 further including an inwardly tapered portion in said valve chamber, said stem extending into said tapered portion of said valve chamber, an enlarged guide portion formed on said valve between said nose portion and said stem, said snubber means comprising a resilient plug positioned between said stem and the tapered portion of said valve chamber, said resilient plug being operative to buffer the rearward movement of said valve when the enlarged guide portion engages the plug and compresses the plug into the tapered portion of the valve chamber and operative to retain the valve in a rearward position for a predetermined interval of time by compressing inwardly about said stem as the plug is driven rearwardly into said tapered portion of said valve chamber.

3. The device of claim 2 further including a split sleeve positioned between said stem and said plug, and a disc positioned between said enlarged guide portion of said valve and said plug.

4. The device of claim 1 in which said barrel chamber and said piston chamber are axially aligned relative to one another and said combustion chamber is positioned at an angle relative to said barrel and valve chambers.

5. The device of claim 1 in which said valve chamber, said combustion chamber, and said barrel chamber are all arranged at an angle relative to each other which is less than a straight angle.

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LIQUID PROPELLANT-ACTUATED DEVICE

Filed Jan. 25, 1968 6 Sheets-Sheet 1

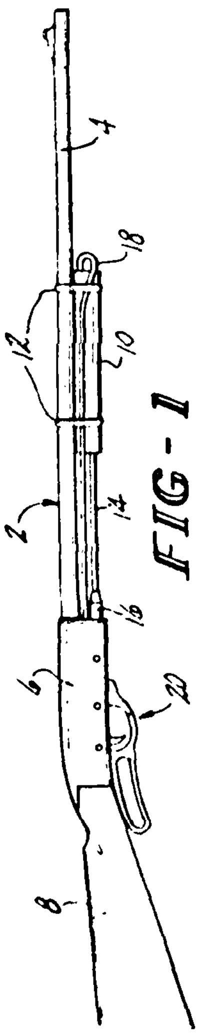

FIG-1

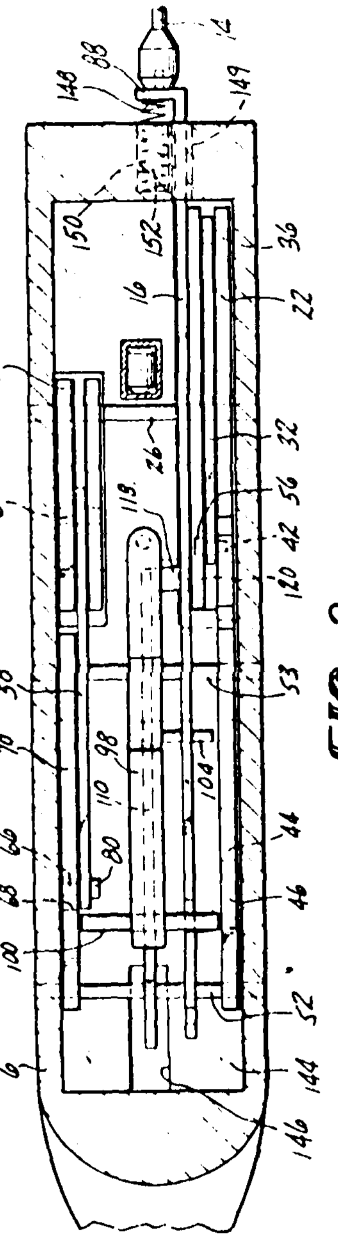

FIG-3

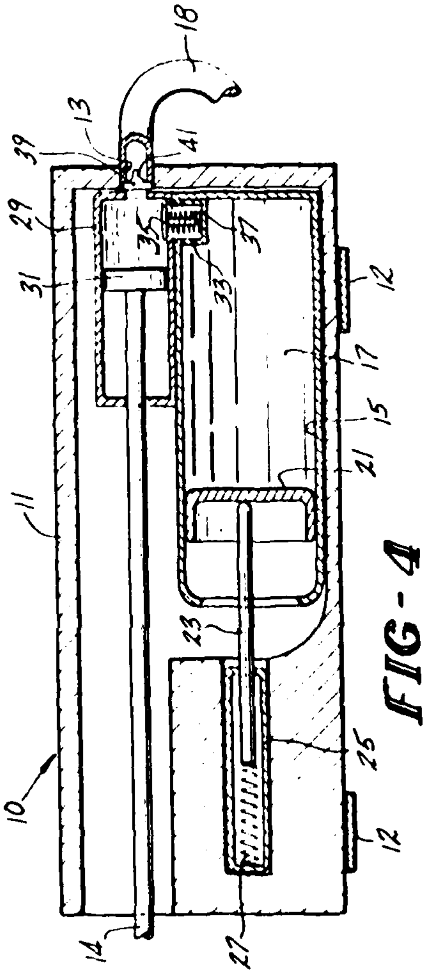

FIG-4

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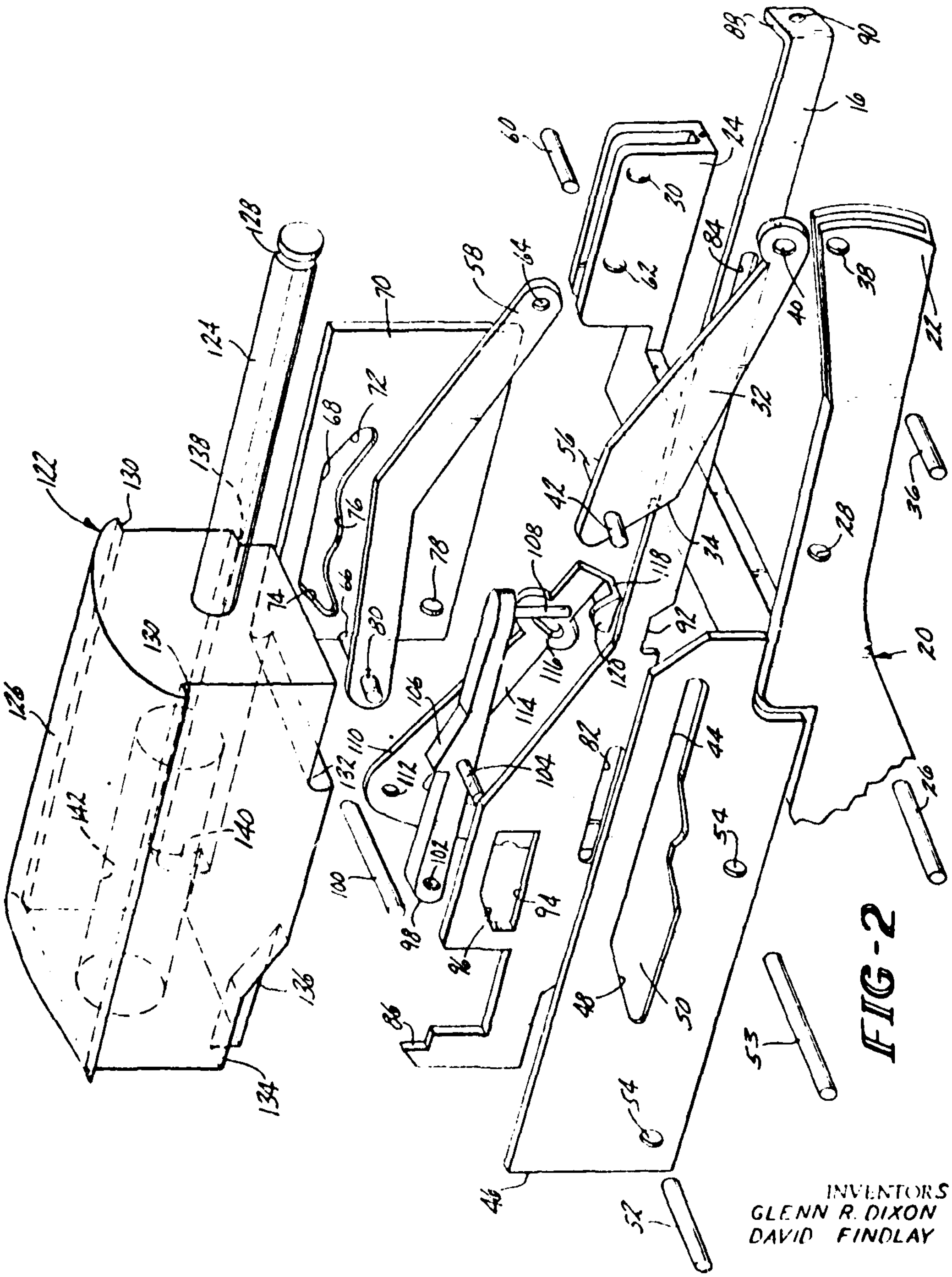

FIG-2

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LIQUID PROPELLANT-ACTUATED DEVICE

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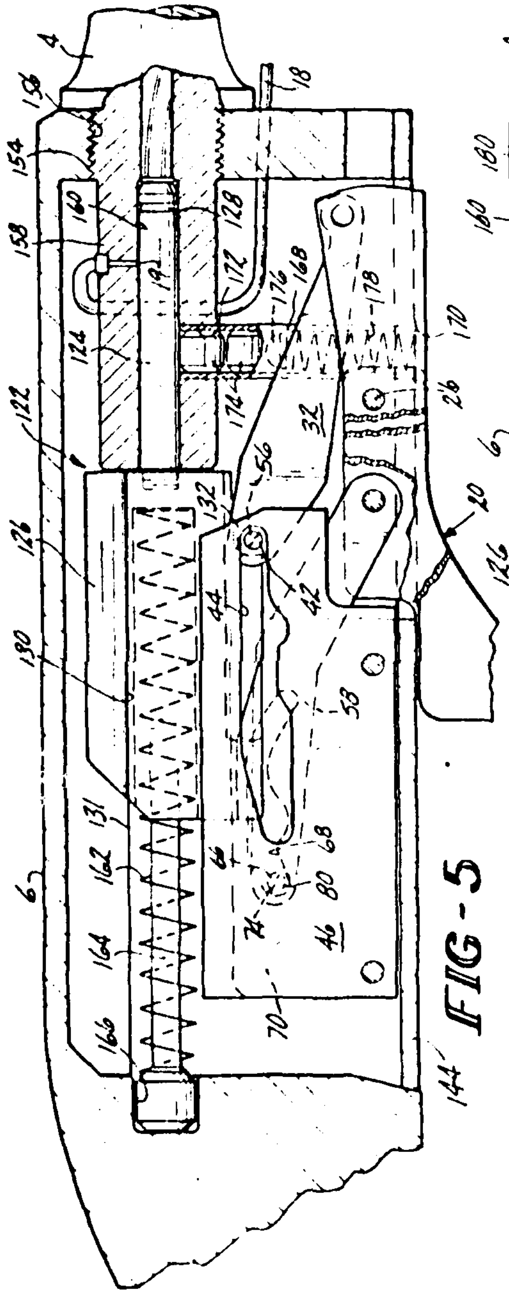

FIG-5

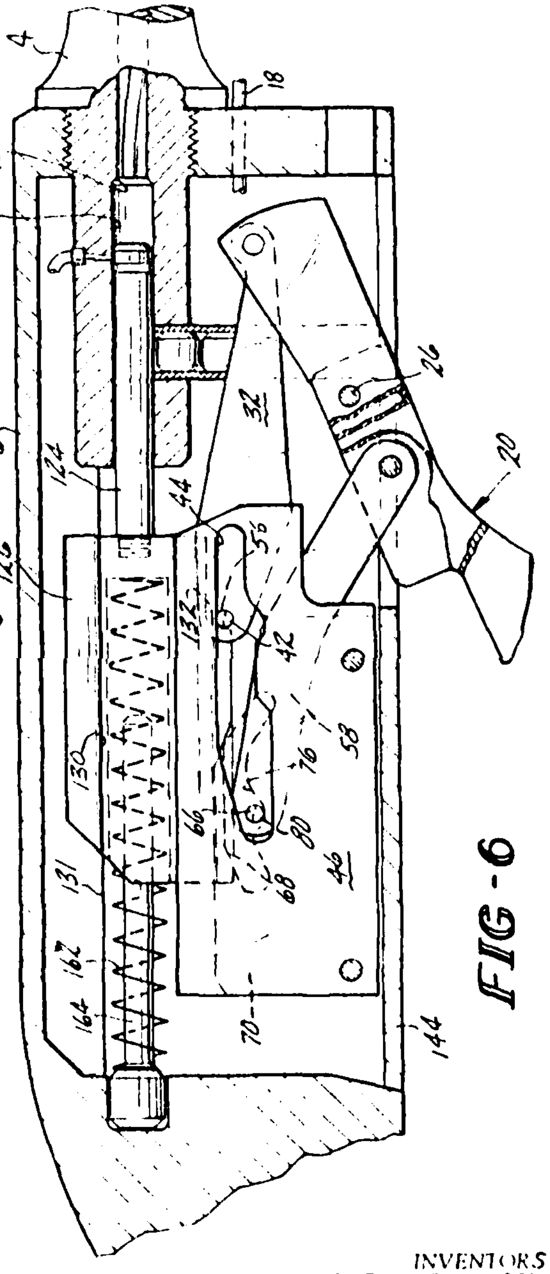

FIG-6

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LIQUID PROPELLANT-ACTUATED DEVICE

Filed Jan. 25, 1968 6 Sheets-Sheet 4

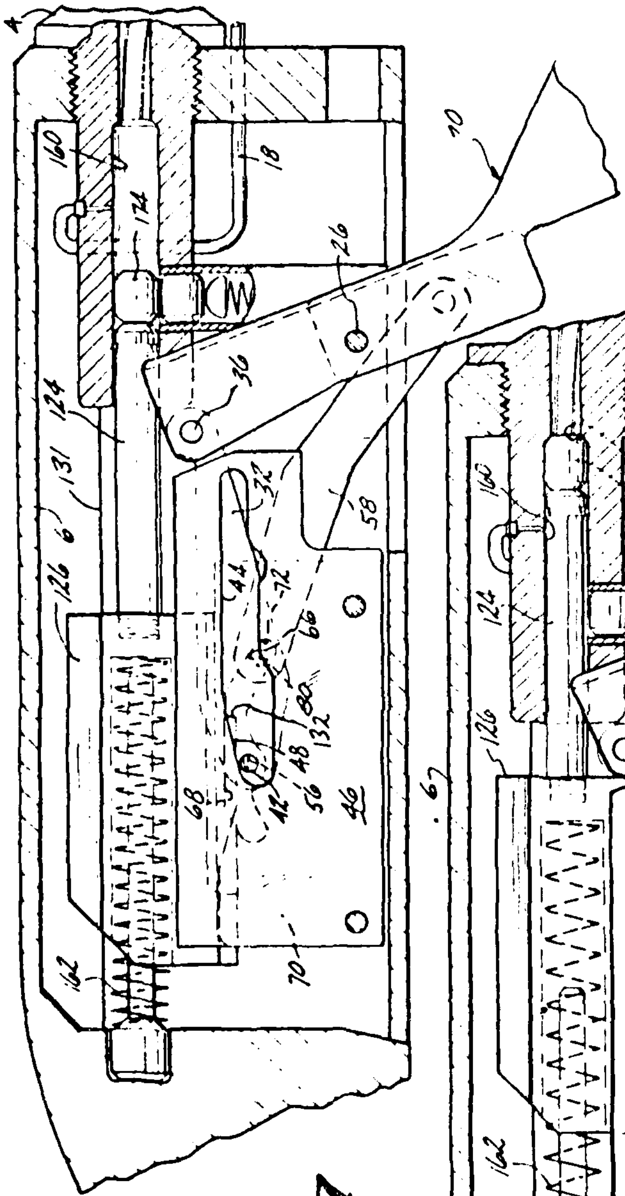

FIG-7

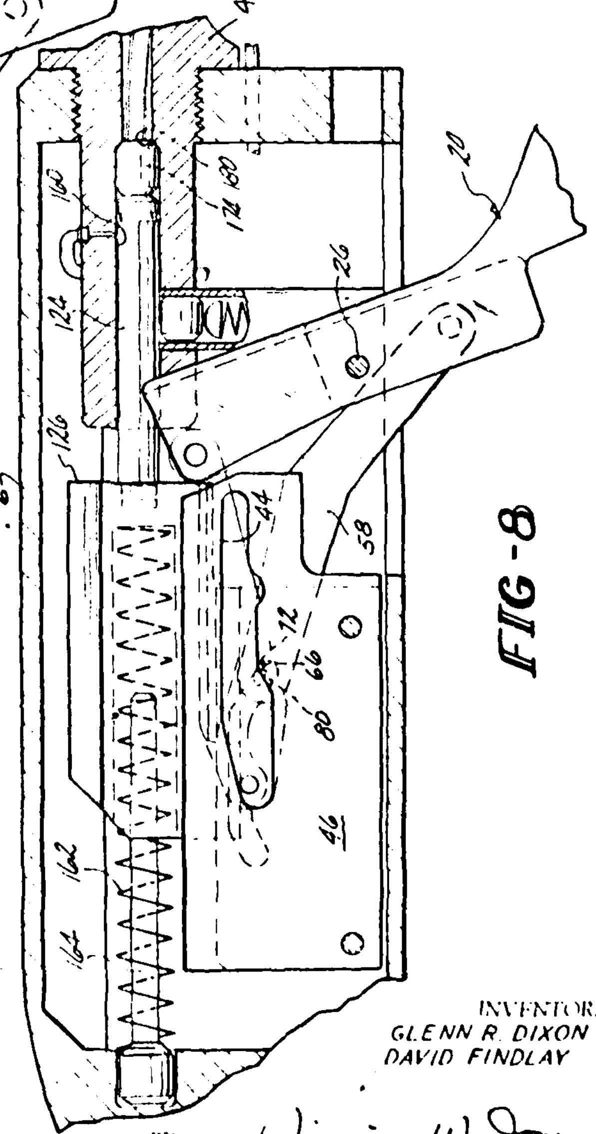

FIG-8

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LIQUID PROPELLANT-ACTUATED DEVICE

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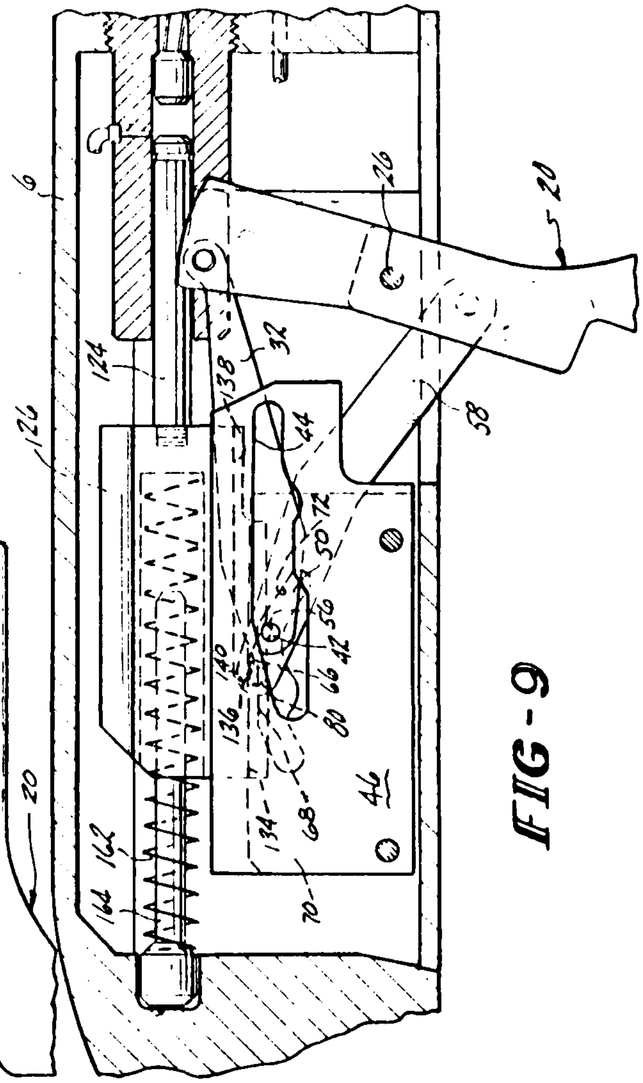

FIG-9

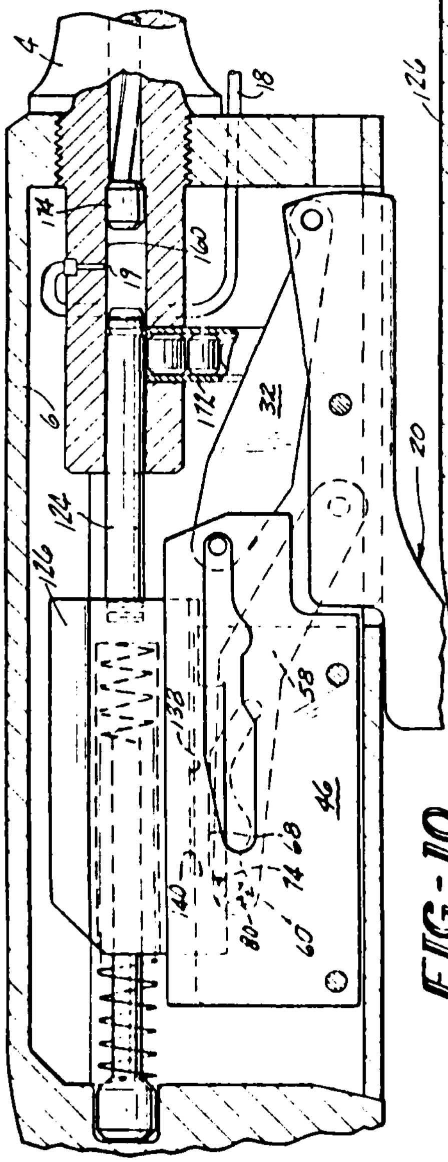

FIG-10

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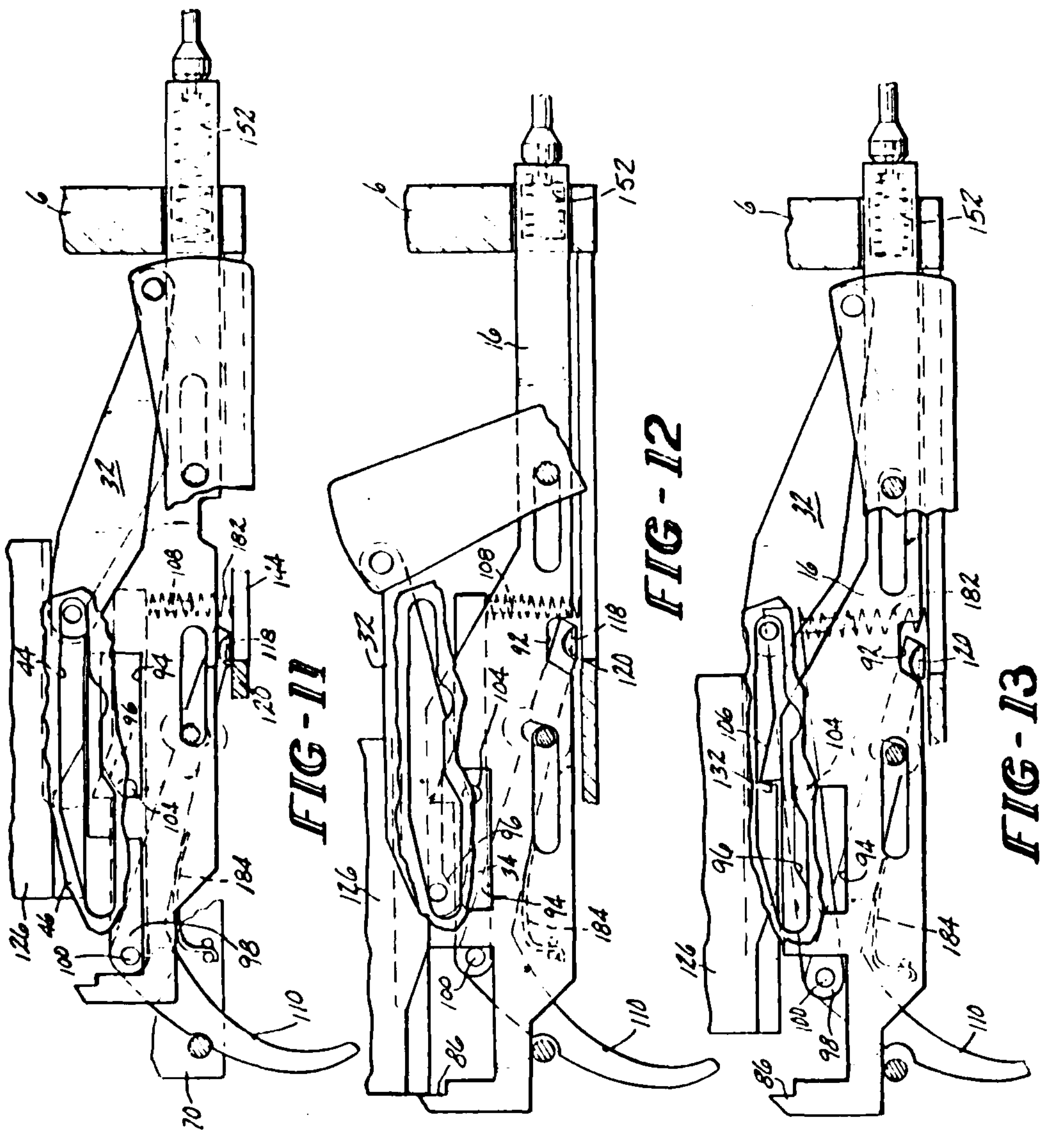

FIG-11

FIG-12

FIG-13

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United States Patent Office

3,455,202

Patented July 15, 1969

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3,455,202

LIQUID PROPELLANT-ACTUATED DEVICE

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Int. Cl. F41c 7/00

U.S. Cl. 89—7 3 Claims

ABSTRACT OF THE DISCLOSURE

A liquid propellant-actuated device having pump means to deliver a charge of liquid propellant to a combustion chamber and having piston means in the combustion chamber operable to adiabatically compress an air-liquid propellant admixture to obtain ignition of the latter. Trigger means operable to sequentially actuate first the pump and secondly the piston, and cocking means to cock both the pump and the piston prior to actuation by the trigger means.

This invention relates to a device which is actuated by the adiabatic compression of a liquid propellant confined in a combustion chamber.

It is known that an admixture of certain liquid propellants and air can be compressed to a very small volume with the heat generated by the compression of the air causing the propellant to ignite. The compression ignition of the propellant produces high pressure gases which can be directed against a projectile or a working piston to act as the propelling agent for the projectile or piston.

Devices which utilize a compressible air-liquid propellant admixture to provide a source of energy must include a compression-combustion chamber which is sufficiently pneumatically sealed to be capable of permitting enough compression to ignite the propellant, and must, furthermore, prevent misdirection of the high pressure gases produced by ignition. The combustion chamber must communicate with one face of the projectile or piston so that the high pressure gases may act upon the projectile or piston to propel the latter. Such a device, desirably, should also include means for separately storing and delivering small charges of propellant to the combustion chamber, thereby permitting use of the device without requiring the operator to, before each shot, transfer a charge of propellant to the combustion chamber from a separate container of propellant carried by the operator. Moreover, it is highly desirable that such a device include triggering means whereby, both the charge of propellant is delivered to the combustion chamber, and the piston is induced to compress the charge by a single actuation. The inclusion of such a triggering feature prevents the possibility that a charge of propellant could be delivered to the combustion chamber, and the device then set aside thereby leaving the propellant charge in the combustion chamber. Thus the chance of one unknowingly picking up a "loaded" device is eliminated.

It is, therefore, an object of this invention to provide a liquid propellant-actuated device of the adiabatic compression type having means for storing a volume of propellant and delivering a charge thereof to a combustion chamber.

It is a further object of this invention to provide a device of the character described having means operable to provide a substantially air-tight seal for the combustion chamber while, at the same time, permitting communication between the combustion chamber and an object to be propelled by the device.

It is a still further object of this invention to provide a device of the character described wherein the object to

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be propelled itself provides a seal for one end of the combustion chamber.

It is yet another object of this invention to provide a device of the character described having means operable to move a piston to a firing position in the combustion chamber while also moving a pump actuator to a cocked position.

It is still another object of this invention to provide a device of the character described having trigger means which is operable on single actuation to initially permit the pump actuator to cause the pump to deliver a charge of propellant to the combustion chamber and subsequently permit the piston to compress an admixture of the propellant charge and air in the combustion chamber.

Other and further objects, and advantages, and features of this invention will be apparent to those skilled in the art from the following descriptions together with the appended drawings, in which:

FIGURE 1 is a side view of a firearm embodiment of this invention;

FIGURE 2 is an exploded view of components of the firearm shown in FIGURE 1 which are disposed within the receiver;

FIGURE 3 is a horizontal sectional view of the receiver portion of the firearm showing the relative position therein of the various components shown in FIGURE 2 with the bolt and combustion chamber being removed for purposes of clarity;

FIGURE 4 is a side sectional view of a pump;

FIGURE 5 is a side sectional view of the receiver showing the piston in the fired position and wherein the trigger, bolt sear, and pump actuator have been omitted for purposes of clarity;

FIGURE 6 is a side sectional view similar to FIGURE 5 showing the initial phase of the cocking lever manipulation;

FIGURE 7 is a side sectional view similar to FIGURE 5 showing the piston in the loading position with a projectile having been fed into the combustion chamber and with the bolt having been disconnected from the cocking lever;

FIGURE 8 is a side sectional view similar to FIGURE 5 showing the piston in the projectile-seating position;

FIGURE 9 is a side sectional view similar to FIGURE 5 showing the initial phase of returning the cocking lever to its original position and wherein the bolt is again connected to the cocking lever;

FIGURE 10 is a side sectional view similar to FIGURE 5 showing the piston in the firing position;

FIGURE 11 is a side sectional view of the receiver showing the bolt in the same position as in FIGURE 5 with the first camming plate being partially cut away and only the first linking lever, the pump actuator, the bolt sear, and the trigger being shown for purposes of clarity;

FIGURE 12 is a side sectional view similar to FIGURE 11 showing the bolt in the same position as in FIGURE 7; and

FIGURE 13 is a side sectional view similar to FIGURE 11 showing the bolt in the same position as in FIGURE 10 with the bolt sear engaging the bolt.

Referring now to FIGURE 1, an embodiment of this invention in the form of a rifle 2 is shown. The rifle 2 includes a barrel 4, a receiver portion 6, and a stock 8. The forearm of the rifle 2 has been removed to more clearly show a pump 10 which contains a volume of liquid propellant and which is mounted on the barrel 4 by means of a pair of brackets 12. A reciprocally movable operating rod 14 is attached to the pump 10 on one hand and to a pump actuator 16 which protrudes from the receiver 6 and which is disclosed in detail hereinafter.

A ~~tubular conduit 18~~ is connected to the forward end of the pump 10, the conduit 18 communicating with a combustion chamber 160 in the receiver 6 by means of a port 19 in the wall of the combustion chamber (see FIGURES 5 and 10) to provide means whereby a charge of liquid propellant can be transferred from the pump 10 to the combustion chamber.

FIGURE 2 is an exploded view of the component parts of the preferred embodiment of the invention which are housed within the receiver 6. A cocking lever 20 having a bifurcated end portion defining a pair of forked, spaced-apart arms 22 and 24 is pivotally mounted on the receiver 6 by means of a pin 26 which passes through appropriate apertures in the receiver walls (not shown) and a pair of apertures 28 and 30 disposed in the arms 22 and 24 respectively. A first linking arm 32 having a camming surface 34 is pivotally connected to the cocking lever arm 22 by means of a pin 36 which passes through a pair of apertures 38 and 40 disposed in the lever arm 22 and the linking arm 32 respectively. It is noted that the aperture 38 is disposed forwardly of the pivot pin 26. The linking arm 32 includes a first laterally protracted pin 42 which extends into a slot 44 cut through a first camming plate 46. The slot 44 is provided with a downwardly sloping camming surface 48 and a downwardly enlarged portion 50. The camming plate 46 is mounted in the receiver 6 by means of a pair of pins 52 and 53 which pass through appropriate apertures in the receiver wall (not shown) and through a pair of spaced-apart apertures 54 disposed in the plate 46. The linking arm 32 further includes a second laterally protracted pin 56 the purpose of which will be set forth hereinafter.

A second linking arm 58 is pivotally connected to the other cocking lever arm 24 by means of a pin 60 which passes through a pair of apertures 62 and 64 disposed in the lever arm 24 and the linking arm 58 respectively. It is noted that the lever arm aperture 62 is disposed rearwardly of the pivot pin 26. The second linking arm 58 includes a first laterally protracted pin 66 which extends into a slot 68 cut through a second camming plate 70. The slot 68 includes two downwardly sloping camming surfaces 72 and 74 at opposite ends thereof and further includes a medial downwardly enlarged portion 76. The second camming plate 70 is mounted in the receiver by means of a pair of apertures 78 (only one of which is shown) which are coaxial with the apertures 54 and which receive the pins 52 and 53. It is noted that the camming plates 46 and 70 are disposed adjacent to opposite sides of the receiver 6. The second linking arm 58 also includes a second laterally protracted pin 80 the purpose of which is set forth hereinafter.

The pump actuator 16 is disposed inwardly adjacent to the cocking lever arm 22 for sliding movement within the receiver 6. The pump actuator 16 includes a pair of elongated slots 82 and 84 through which pass the pins 53 and 26 respectively. The pump actuator 16 further includes an upwardly extending shoulder 86 at one end thereof and a laterally bent terminal portion 88 having an aperture 90 at the other end thereof. A notch 92 is cut upwardly into the bottom edge of the pump actuator 16. The pump actuator further includes a window 94 having a downwardly sloping camming surface 96 therein.

A bolt sear 98 is disposed inwardly adjacent to the pump actuator 16 for pivotal movement about a pin 100 which passes through an aperture 102 in one end of the bolt sear 98. The bolt sear 98 includes a laterally directed lug 104 which extends through and beyond the window 94 in the pump actuator 16. An upwardly extending tooth 106 is disposed on the upper surface of the bolt sear 98, and a downwardly extending spring guide 108 is disposed on the lower surface of the sear.

A generally V-shaped trigger member 110, having an aperture 112 for pivotal connection to the pin 100, is disposed adjacent to the bolt sear 98. The trigger member includes a forwardly and downwardly extending leg 114 having a generally oval aperture 116. A laterally extending finger 118 having an upwardly bent terminal portion 120 is positioned at the lower end of the leg 114, the terminal 120 being substantially coplanar with the pump actuator 16.

A piston assembly, indicated generally by the numeral 122, is mounted in the receiver 6 for reciprocating movement therein. The piston assembly 122 includes a piston portion 124 and a head or bolt portion 126 connected thereto. The piston portion 124 may, for convenience in assembly, be screwed into the front face of the bolt portion 126. The piston portion 124 may include one or more gas grooves 128 adjacent the forward end thereof to increase the sealing properties of the piston. The bolt or head portion 126 includes a pair of laterally extended flanges 130 for sliding engagement with complementary shoulders 131 in the walls of the receiver (see FIGURES 5–10). A downwardly extending transverse shoulder 132 is formed on the bottom surface of the bolt 126. A first notch 134 having a downwardly and forwardly inclined camming surface 136 is cut into the lower edge on one side of the bolt 126, the first notch 134 extending through the rear face of the bolt 126. A second notch 138 having a closed rear face 140 is cut into the lower edge of the other side of the bolt 126, the second notch 138 extending through the front face of the bolt. The bolt 126 further includes a cylindrical bore 142 for the reception of a spring and spring guide (see FIGURES 5–10).

Referring now to FIG. 3, the various components referred to above are shown as mounted in the receiver 6 with the piston assembly 122 being removed for purposes of clarity. A bottom plate 144 closes the bottom of the receiver 6, the bottom plate having a slot 146 through which the trigger 110 extends. The pump actuator 16 extends through a slot 149 in the front face of the receiver 6 and the laterally bent terminal portion 88 of the pump actuator 16 is connected to the pump operating rod 14 by means of a screw 148. A spring member 152 is disposed in a well 150 in the front face of the receiver 6. The spring 152 is also connected to the terminal portion 88 of the pump actuator 16 by means of the screw 148 to bias the pump actuator 16 toward the pump 10.

FIGURE 4 discloses an embodiment of a pump, indicated generally by the numeral 10, which can be utilized with this invention. The pump includes a hollow housing member 11 having an aperture 13 in one end through which the conduit 18 passes. A container 15 for a volume of liquid propellant 17 is disposed in the housing 11, the container 15 having a movable end-wall member 21 therein. The volume of liquid propellant 17 is maintained at a substantially constant pressure by means of a rod 23 which bears against the end-wall member 21, the rod 23 being slidably housed in a guide 25 and biased to the right by a spring member 27. A cylinder 29 having a piston 31 slidably mounted therein is disposed adjacent to the propellant container 15. The pump operating rod 14 is rigidly affixed to the piston 31 to effect movement of the piston within the cylinder 29. Fluid communication between the container 15 and the cylinder 29 is established by means of a one-way check valve 33 having a head member 35 which is biased downwardly by a spring 37. The sides and bottom of the valve 33 are perforated to permit the propellant to flow therethrough. The conduit 18 communicates with the cylinder 29 through a one-way check valve 39 in the form of a resilient body of rubber or the like. The valve 39 includes a conical portion 41 having a plurality of fingers formed therein by means of a number of radially extending cuts in a known manner.

The pump 10 operates in the following manner. As is readily apparent from FIGURE 4, when the piston 31 is moved to the left, the pressure within the cylinder

29 falls. The valve 33 is such that when the pressure in the ~~cylinder 29~~ falls below a predetermined valve, the valve head 35 is moved upwardly against the action of the spring 37 by the pressure in the container 15 to permit the propellant to flow from the container 15 into the cylinder 29. At the same time, the drop in pressure within the cylinder 29 causes the valve 39 to close by collapsing the resilient fingers against each other. When the piston 31 is driven to the right, the pressure within the cylinder 29 increases. The increase in pressure causes the valve 33 to close and the valve 39 to open. Thus the propellant is drawn from the container 15 into the cylinder 29 by moving the piston 31 to the left, and the propellant is then expelled from the cylinder 29 into conduit 18 by moving the piston 31 to the right. It is noted that when the pressure within the cylinder 29 increases above a predetermined value, the resilient fingers on the valve 39 are forced apart and the valve is thus opened.

FIGURES 5–10 disclose the operation of the cocking lever 20 to ready the piston assembly 122 of the firearm for firing. For purposes of clarity, the bolt sear 98, the pump actuator 16, and the trigger 110 have been removed from the receiver 6. As is shown in FIGURES 5–10, the barrel 4 has a threaded portion 154 which is screwed into a threaded aperture 156 in the front wall of the receiver 6. A part 158 of the barrel 4 extends beyond the threaded portion 154 and into the receiver 6 to define a combustion chamber 160. It is noted that the propellant conduit 18 communicates with the combustion chamber 16 through a port 19.

In FIGURE 5, the piston 124 is shown in the fired position with the bolt 126 being urged into its forwardmost position in the receiver 6 by means of a spring 162 disposed about a spring guide 164, which is mounted in a recess 166 in the rear wall of the receiver. Both the spring 162 and spring guide 164 extend into the cylindrical bore 142 in the bolt 126. The cocking lever 20 is shown in its normal position with the first pin 42 on the first linking arm 32 being disposed in the forwardmost portion of the slot 44 in the first camming plate 46. The second pin 56 on the first linking arm 32 is disposed forwardly adjacent to the transverse shoulder 132 on the bolt 126. The first pin 66 on the second linking arm 58 is disposed adjacent the camming surface 74 in the rearward portion of the slot 68 in the second camming plate 70.

A projectile magazine 168 is shown partially cut away, the projectile magazine 168 extending through an aperture 170 in the receiver bottom plate 144, and through an aperture 172 in the wall of the combustion chamber 160, with the magazine 168 being removably connected to the plate 144 in any known manner. A plurality of projectiles 174 are disposed in the magazine 168, the projectiles 174 being urged upwardly toward the combustion chamber 160 by a follower member 176 biased upwardly by a spring 178 disposed in the magazine 168. It is noted that the uppermost projectile in the magazine 168 is urged into contact with the side of the piston 124 when the latter is in the fired position.

FIGURE 6 shows the initial stages of the first cocking movement of the cocking lever 20. The cocking lever 20 is pivoted in a counter clockwise direction about the pin 26 thereby pushing the first linking arm 32 rearwardly and pulling the second linking arm 58 forwardly in the receiver 6. The first pin 42 on the linking arm 32 moves rearwardly in the slot 44 in the first camming plate 46 and the second pin 56 moves rearwardly into engagement with the transverse shoulder 132 on the bolt 126. Continued pivoting of the cocking lever 20 thus moves the bolt 126 rearwardly in the receiver 6 and the piston 124 rearwardly in the combustion chamber 160. Rearward movement of the bolt 126 in the receiver 6 thus compresses the spring 162. As the first pin 66 on the second linking arm 58 moves forwardly through the slot 68 in the second camming plate 70, the second pin

80 contacts the rearwardly moving bolt 126 and is downwardly displaced into the downwardly enlarged medial portion 76 of the slot 68, thereby permitting the bolt 126 to slide rearwardly past the pin 80.

FIGURE 7 shows the piston 124 in the loading position wherein the piston 124 has been moved rearwardly in the combustion chamber 160 sufficiently to permit the uppermost projectile 174 to be moved up into the combustion chamber 160 in front of the piston 124. The cocking lever 20 has been pivoted to its extreme counterclockwise position causing the first pin 42 on the first linking arm 32 to engage the camming surface 48 at the rear of the slot 44. The engagement between the pin 42 and the camming surface 48 causes the linking arm 32 to pivot downwardly about the pin 36 thereby disengaging the second pin 56 from the transverse shoulder 132 on the bolt 126. The bolt 126 is thus free to be driven forwardly in the receiver 6 by the spring 162. As shown in FIGURE 7, the bolt 126 has just begun its forward movement in the receiver 6. It is noted that the first pin 66 on the second linking arm 58 has engaged the camming surface 72 on the front portion of the slot 68 thereby moving the second pin 80 downwardly out of the path of the forwardly moving bolt 126.

FIGURE 8 shows the piston 124 in the projectile-seating position. The bolt 126 has been driven forward by the spring 162 thereby moving the piston 124 and projectile forward in the combustion chamber 160. The piston 124 drives the projectile 174 against an inwardly extending frusto-conical shoulder 180 at the forward end of the combustion chamber 160, the projectile 174 thereby effecting a substantially air-tight seal with the shoulder 180, to sealing the front end of the combustion chamber 160.

FIGURE 9 shows the initial phase of the second cocking movement wherein the cocking lever 20 is returned to its normal position. The cocking lever 20 is pivoted in a clockwise direction about the pin 26 thereby pushing second linking arm 58 rearwardly and pulling the first linking arm 32 forwardly in the receiver 6. As the second linking arm 58 moves rearwardly in the receiver 6, the first pin 66 thereon moves rearwardly and upwardly in the camming portion 72 of the slot 68. The second pin 80 on the second linking arm 58 is thus moved rearwardly and upwardly into engagement with the rear face 140 of the second notch 138 on the bolt 126. Continued rearward movement of the pin 80 causes the bolt 126 to move rearwardly thus compressing the spring 162. Forward movement of the first linking arm 32 causes the first pin 42 thereon to move forwardly through the slot 44 in the first camming plate 46, and also causes forward movement of the second pin 56 thereon. As the second pin 56 moves forward through the receiver and the bolt 126 moves rearward through the receiver, the second pin 56 is brought into contact with the camming surface 136 on the bolt notch 134. The first linking arm 32 is thus deflected downwardly by the camming surface 136 with the first pin 42 moving into the downwardly enlarged portion 50 of the slot 44. The bolt 126 and the first linking arm 32 thus clear each other as they move in opposite directions in the receiver 6.

FIGURE 10 shows the piston 124 in the firing position with the cocking lever 20 having been returned to its normal position. The linking arms 32 and 58 have been returned to their original positions as shown in FIGURE 5. It is noted that the second pin 80 on the second linking arm 58 has been moved downwardly out of engagement with the rear face 140 of the bolt notch 138 by a downward camming movement of the first pin 66 as it engages the rearward camming portion 74 of the slot 68. The front end of the piston 124 is disposed forwardly of the magazine aperture 172 and provides a substantially air-tight seal at the rear of the combustion chamber 160. It is noted that, in the firing position, the propellant port 19 is between the seated projectile 174

and the front face of the piston 124. The bolt 126 is releasably latched in the position shown in FIGURE 10 by the bolt sear 98 as hereinafter described.

FIGURES 11–13 show the operation of cocking the pump actuator 16 and the interrelation between the bolt 126, the bolt sear 98, the trigger 110, the pump actuator 16 and the first linking arm 32. In FIGURES 11–13, portions of the receiver 6, the bolt 126, the cocking lever 20, and the first camming plate 46 have been cut away for purposes of clarity. In addition, the second camming plate 70, the second linking arm 58, the piston 124, and the combustion chamber 160 have been omitted for clarity.

In FIGURE 11 the bolt 126 is in the same position as shown in FIGURE 5. The pump actuator 16 is in a driven position and is biased thereto by the spring 152. The laterally directed lug 104 on the bolt sear 98 is in engagement with the camming surface 96 on the pump actuator window 94 thus causing the bolt sear 98 to pivot about the pin 100, against the bias of a spring 182 and out of engagement with the bolt 126. The upwardly bent terminal portion 120 on the laterally extending trigger finger 118 engages the lower surface of the pump actuator 16 thus pivoting the trigger 110 about the pin 100 against the bias of a blade spring 184.

FIGURE 12 shows the bolt 126 in the same position as in FIGURE 7. As the bolt 126 is moved from the position in FIGURE 11 to the position in FIGURE 12, the rear face of the bolt 126 engages the upwardly extending shoulder 86 on the pump actuator 16 and the latter is cocked by moving rearwardly, compressing the spring 152. The pump actuator 16 is moved sufficiently to the rear to permit the terminal 120 on the trigger finger 118 to pivot upwardly into the notch 92 in the pump actuator 16 under the influence of the spring 184. Rearward movement of the pump actuator 16 moves the camming surface 96 on the pump actuator window 94 out of engagement with the bolt sear lug 104, but the latter is then engaged by the camming surface 34 on the linking arm 32 to continue to hold the bolt sear 98 out of engagement with the bolt 126.

FIGURE 13 shows the bolt in the same position as in FIGURE 10 with the first linking arm 32 having been returned to its normal position. The pump actuator 16 is retained in a cocked position by engagement between the trigger finger terminal 120 and the wall of the pump actuator notch 92. The pump actuator window camming surface 96 is thus rearwardly spaced apart from the bolt sear lug 104. Since the first linking arm 32 has returned to its normal position, the bolt sear 98 is free to pivot under the influence of the spring 182 in a counterclockwise direction about the pin 100 thereby bring the bolt sear tooth 106 into engagement with the transverse bolt shoulder 132, thus searing the bolt 126 in the firing position.

The firearm is fired by manually pulling the trigger 110 in a clockwise direction. The trigger finger terminal 120 is thus moved downwardly out of engagement with the pump actuator notch 92 and the pump actuator 16 moves to the right under the influence of the spring 152. The pump 10 is thus caused to deliver a charge of liquid propellant to the combustion chamber 160. At the end of the forward stroke of the pump actuator 16, the pump actuator window camming surface 96 engages the bolt sear lug 104 causing the sear 98 to pivot downwardly disengaging the tooth 106 from the bolt shoulder 132. The bolt 126 is then free to travel forward under the influence of the spring 162, thereby driving the piston 124 forward through the combustion chamber 160 to compress the admixture of air and propellant and ignite the latter.

A propellant which may be used with this invention is a mixture of 60% ethyl nitrate and 40% n-propyl nitrate. The ignition pressure of this propellant at ambient temperature is above 500 p.s.i., therefore, the seated projectile and the piston must provide a sufficiently air-tight seal to reach such a pressure when the piston is driven forward. After ignition, the pressures in the combustion chamber are exceedingly high, the exact pressures depending on the charge and particular propellant. The result of this sharp increase in pressure is that the projectile is expelled from the combustion chamber through the barrel.

It is thus readily apparent that this invention advantageously provides a device which includes a pump for storing and delivering a charge of liquid propellant to a combustion chamber wherein an admixture of air and propellant is ignited by adiabatic compression. Moreover, this invention provides a single triggering means for serially actuating the pump and compression means in an irreversible sequence so that once the trigger is pulled to actuate the pump, the compression of the air-liquid propellant admixture automatically follows.

Since many changes and variations of the disclosed embodiment of this invention may be made without departing from the inventive concept, it is not intended to limit the invention otherwise than as required by the appended claims.

What is claimed is:

1. In a liquid propellant-actuated device having a combustion chamber, pump means operable to deliver a charge of liquid propellant to the combustion chamber, and spring loaded piston means movably mounted in the combustion chamber to compress and ignite an admixture of air and propellant, the improvement comprising:

(a) a cocking lever connected to said device for pivotal movement from a first position to a second position and return;

(b) first linking means movably connected to said cocking lever for releasable engagement with said piston means and operative to move said piston means from a fired position to a loading position when said cocking lever is moved from said first position to said second position;

(c) second linking means movably connected to said cocking lever for releasable engagement with said piston means and operative to move said piston means from a projectile-seating position to a firing position when said cocking lever is moved from said second position to said first position; and

(d) means connected to said device operative to disengage said first linking means from said piston means when the latter is in said loading position, and operative to disengage said second linking means from said piston when the latter is in said firing position.

2. In a liquid propellant-actuated device having a combustion chamber, pump means operable to deliver a charge of liquid propellant to the combustion chamber, and spring loaded piston means movably mounted in the combustion chamber to compress and ignite an admixture of air and propellant:

(a) a cocking lever connected to said device for pivotal movement between a first position and a second position;

(b) linking means connected to said cocking lever for releasable engagement with said piston means, said linking means being operative to initially move said piston means from a fired position to a loading position when said cocking lever is moved from said first position to said second position, and said linking means being operative to subsequently move said piston means from a projectile seating position to a firing position when said cocking lever is returned from said second position to said first position,

(c) means operative to disengage a first portion of said linking means from said piston means when the latter is in said loading position, and to disengage the remainder of said linking means from said piston means when the latter is in said firing position;

(d) sear means for releasably retaining said piston means in said firing position;

(e) a pump actuator connected to said pump means,

said pump actuator being movable between a cocked position and a driven position to operate said pump means, said pump actuator including a portion for engagement with said piston means whereby movement of said piston means to said loading position results in movement of said pump actuator to said cocked position;

(f) biasing means connected to said pump actuator to urge the latter toward said driven position;

(g) trigger means for releasably retaining said pump actuator in said cocked position against the action of said biasing means; and

(h) camming means for engagement with said sear means when said pump actuator is in said driven position, said camming means being operative to disconnect said sear means from said piston means thereby causing the latter to be driven to said fired position after operation of said pump means.

3. The device as defined in claim 1 or 2, further comprising magazine means communicating with said combustion chamber for automatically feeding ones of a plurality of projectiles into said combustion chamber when said piston means is in said loading position.

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U.S. Cl. X.R.

89—33

U.S. FIRM PATENTS

Patent Number: 2,981,153
Author: E. J. Wilson, Jr., et al
Title: Fuel Injection Device
Date: April 25, 1961

Patent Number: 4,148,245
Author: Robert D. Steffanus, Pittsburg, PA; David R. Anderson, Pittsburg, PA
Title: Fluid Propellant Projectile Firing Device
Date: April 10, 1978

FUEL INJECTION DEVICE

Filed Nov. 14, 1952 2 Sheets-Sheet 1

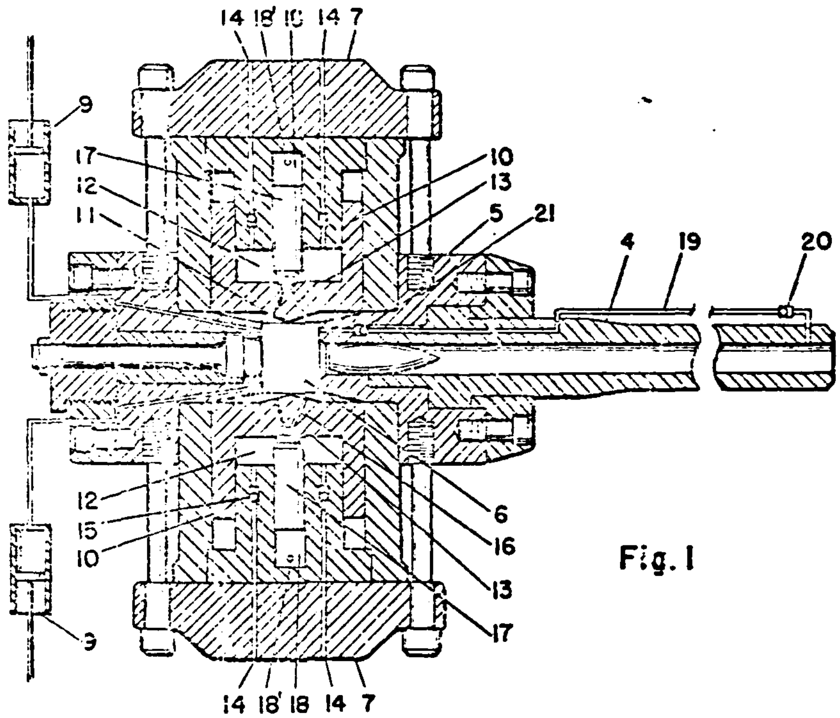

Fig. 1

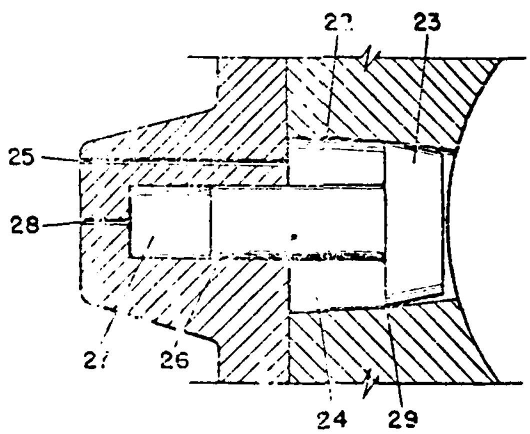

Fig. 2

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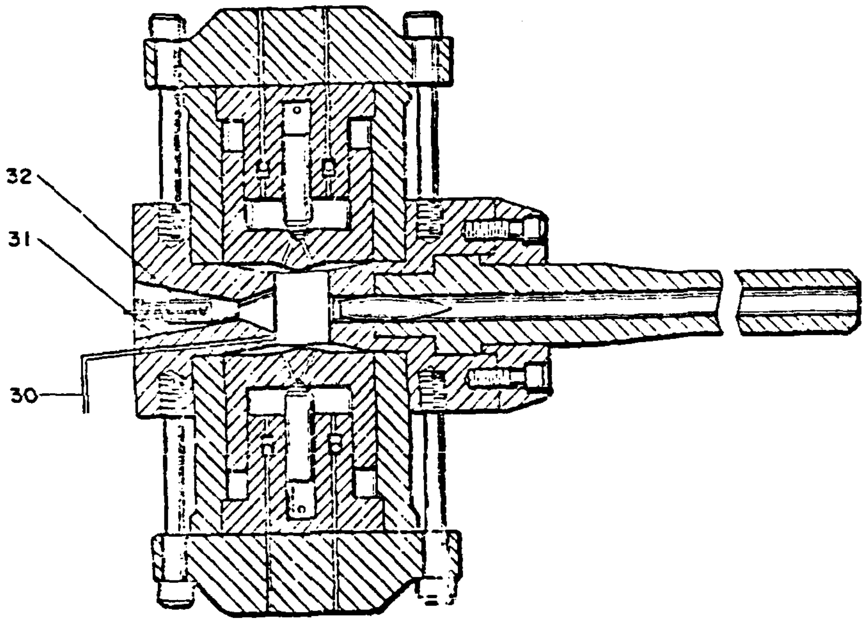

Fig. 3

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FUEL INJECTION DEVICE

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14 Claims. (Cl. 89—7)

This invention relates to improvements in the injection of fuel into combustion chambers wherein combustion pressure is utilized to inject the fuel into the combustion chamber. The invention is particularly useful in the field of liquid fuel guns and launchers.

A principal object of the invention is the provision of improved means for injecting fuel into combustion chambers.

An important object of this invention is to provide means whereby all the advantages that should accompany a gun actuated by liquid propellants may be realized.

Another object of this invention is to provide means whereby liquid propellant may be introduced into a gun in an almost continuous flow, and automatically and repeatedly be injected into the combustion chamber by means of a device which utilizes the combustion pressure.

A further object of this invention is to provide a means of fuel injection which is simple and conducive to very rapid rates of fire.

Other objects and advantages of the invention will become apparent during the course of the following description. in which the principles of the invention are more particularly described in their application to liquid fuel guns.

The basic concept of a liquid fuel gun is characterized by its simplicity. Fundamentally, the gun consists of a mechanism for propelling projectiles from a tube or barrel by means of the pressure resulting from the combustion of a liquid oxidizer and a liquid fuel injected into the breech of the tube. The liquids employed are usually hypergolic in nature, i.e. self-igniting, and the desirable combinations are those which yield high temperatures upon combustion and whose combustion products possess low molecular weights. As a result of the successful application of certain hypergolic combinations, hydrogen peroxide and hydrazine for example, it has become apparent that the liquid propellant gun can be vastly superior to the conventional powder actuated gun for many military applications. Among the primary advantages in the use of liquids instead of double base nitrocellulose powders for the launching of missiles are the ability to achieve control over the burning rate of the charge, which ultimately results in the elimination of undesirable peak chamber pressures, and to effect a considerable saving in gun bulk. In addition, the higher propellant impetus possible with some liquid fuels by reason of lower molecular weights of the product gas and greater heats of combustion lowers the charge to mass ratios for a specific muzzle velocity. This latter

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factor is influential in easing the problem of handling huge quantities of charge when extremely high muzzle velocities are desired. Moreover, the maximum muzzle velocities obtainable with liquid fuels are greater than for the conventional powder propellants.

Prior to this invention liquid powered guns had been limited to a single-shot mechanism. Moreover, injection of the hypergolic components into the combustion chamber could be accomplished only by utilizing the gaseous pressure obtained by firing an auxiliary solid propellant charge. This resulted in the loss of many of the advantages that a liquid system should offer. For example, the use of liquids implies the elimination of shell casings and attendant cost and handling problems. The externally pressurized gun, referred to above, still involved these impediments. Moreover, it is doubtful whether any effective control could be achieved over the injection rate and consequent pressure-time relationships in the combustion chamber when injection is dependent upon external pressurization. These defects are overcome and many more of the potential advantages of a liquid system are realized by the present invention.

The invention may be briefly summarized as comprising the regenerative utilization of combustion pressure resulting from the injection and reaction of fuels.

In the accompanying drawings which form a part of this specification:

Fig. 1 is a cross-sectional view of a 37 mm. liquid fuel gun embodying the principles of the invention;

Fig. 2 is a fragmentary sectional view of an injector unit wherein a valving effect is an inherent function of the moving piston; and

Fig. 3 is a cross-sectional view of a liquid fuel gun having a recoilless feature wherein the means for the initiation of the first firing and the means for maintenance of subsequent firing are the same.

The basic features of the invention may be observed in quasi-schematic form by reference to Fig. 1, which represents a 37 mm. gun. A barrel or tube 4 is affixed to a gun block 5 and a means is provided (not shown) whereby projectiles may be quickly inserted in the breech end of the block. Conventional features of this gun such as barrel, projectile loader, breech, etc., are unrelated to the problem of propellant injection and the design of these secondary components can take any standard form depending on the caliber and gun performance desired. A combustion chamber 6 is located in the block and two opposed piston-cylinder propellant injectors 7 are inserted into side openings communicating with the chamber. The required amounts of liquid fuel and oxidant are placed in their respective injectors. With the generation of an initial pressure pulse in the combustion chamber, in this instance provided by pilot injection of small amounts of the hypergolic components by means of a mechanical feed 9, the injection cycle is commenced.

In Fig. 1 the injector is shown with members displaced in the loaded state consisting of movable pistons 10 having a large area exposed to the combustion zone and designated the combustion face 11. A smaller area exposed to a metered volume of propellant in chamber 12 is identified as injection face 13. During the loading cycle, the reactive liquid enters the injector through the propellant supply lines 14 which are provided with check valves 15 to prevent reverse flow during injection.

In the 37 mm. gun herein described, suitable total combustion face areas 11 and total injection face areas 13 are 66.37 square inches and 28.37 square inches, respectively, resulting in an area ratio of the differential area piston of 2.34. The areas are selected to provide an optimum injection rate for a desired pressure-time relationship in the chamber, taking into account the increase in chamber volume during injection by reason of the outward motion of the pistons and motion of the projectile along the barrel. Not only is the selection of the area ratio governed by considerations of a desired pressure-time curve but selection of the other features of the injector is also governed by that factor.

As indicated previously, the ejection stroke is initiated by the presence of compressed gas in the combustion chamber obtained by bringing together small quantities of the propellants with an auxiliary mechanical feed. This pressure acting against the combustion face of the piston results in a pressure build-up in the zone of the metered volume of propellant in accordance with the area ratio of the combustion face to the smaller injection face. Thus, the differential-area piston serves to generate an injection pressure always proportionately higher than the combustion chamber pressure. Flow of propellant through orifices 16 and into the combustion chamber will occur when the injection pressure is sufficiently great to actuate the poppet valves 17. Combustion of the injected propellants, which eventually reaches its climax in the launching of the missile, is reflected in even greater chamber and injection pressures, so that the injection rate increases during the injection stroke in accordance with the increase in pressure differential between the combustion chamber and the metered volume chamber. This phenomenon is a regenerative or self-energizing injection. The poppet valves 17 are maintained under pressure by means of pressurized gas supplied to chambers 18 through conduits (not shown) terminating at outlets 18'.

A desirable pressure-time relationship in the combustion chamber is dependent upon the rate of injection which in turn is dependent upon many variables such as area ratio, orifice size, valve control, etc. A desirable pressure-time relationship is characterized by the absence of sharp peak pressures in the combustion chamber which are associated with inefficient acceleration of the projectile. A maximum muzzle velocity is obtained for a given amount of charge when the area under the pressure time curve is maximum. Therefore, when comparing powder with liquids, in addition to the advantage gained in a liquid gun because of the high propellant impetus possible with liquid fuels, the control of pressure-time relationships in the combustion chamber also results in contributing to higher muzzle velocities for any given charge-mass ratio. Comparison of the ballistic efficiency of liquid and powder actuated guns leaves no doubt of the superiority of the former.

The reloading stroke is now automatically commenced when the injection pressure falls to a pre-determined value at the end of the firing, closing the poppet valves. An excess of propellant supply line pressure over the pressure in the metered volume chamber opens the supply check valves permitting propellant to flow into the system accompanied by the return of the movable piston to its original (loaded) position. Simultaneously with the completion of a firing cycle, a new projectile is placed in the breech by devices not shown and the cycle may be repeated by the re-introduction into the combustion chamber of part of the combustion gas from the barrel. This may be accomplished, for example, by having part of the combustion gas in the barrel stored under pressure in line 19 when a check valve 20 at the entrance of the line is opened. When the injector is loaded and the projectile is inserted in the gun, a control valve 21 is opened electrically or by some other suitable means and the gas is introduced into the combustion chamber. Hence, the cycles may be continued indefinitely and as rapidly as projectiles can be loaded into the breech for injection, and combustion can be accomplished in a matter of milliseconds. Therefore, by utilizing a differential-area piston to translate a relatively low pressure into a very high injection pressure, a method has been devised whereby the combustion pressure itself can be employed for the injection of the reactants, and a gun has been provided which can exploit the advantages that a liquid system should offer.

An injector dependent upon a differential-area piston may be termed a "self-energizing" or "regenerative" injector. Obviously a large number of designs and component arrangements are possible. There may be more than one injector pair used in the operation of the gun. Similarly, a single injector may be used provided suitable liquid monofuels are available. It makes no difference whether the injector units are opposed, coupled, concentric, or otherwise displayed as long as appropriate differential-area pistons are employed in accordance with the invention.

An alternative form of injector unit is depicted in Fig. 2. This example is only one of a number of possible configurations whereby the piston itself can be made to perform a valving and metering function. This effect may be obtained by tapering both the cylinder walls 22 and the piston head 23 as is shown in Fig. 2. By suitably shaping the tapered sections, vigorous mixing of the propellant components and desired rates of injection may be insured.

Propellant is metered into the metered volume chamber 24 through conduit 25 in quantities insufficient to interfere with the proper displacement of the piston 26. A suitable pressure is maintained on the piston by means of compressed gas supplied to chamber 27 through conduit 28. As the piston is displaced by rising combustion chamber pressures, the rim of the piston head and the tapered cylinder walls form a variable area orifice which grows larger with rising combustion chamber pressures. It should be noted that when the injector is in a loaded state, a line contact sealing effect is obtained at 29. This is one of the most satisfactory of the sealing effects.

The initiation and the maintenance of the firing cycles of the gun may be accomplished in various ways. It is to be noted at this point that although the initiation of the firing cycle and the initiation of injector action are one and the same, the maintenance of the firing cycles and the sustaining of injector action should be clearly distinguished. The following account deals with initiation and maintenance of firing cycles.

Fig. 1 illustrates the method of first initiating the firing from an external pressure source and thereafter maintaining it by the return of part of the pressurized combustion gas. Fig. 3 illustrates a form of the invention wherein the means for initiation and maintenance of the firing cycles are the same. In Fig. 3 the activating pressure is obtained from an external source of pressure gas through conduit 30. This source may be as portable as the gun itself, and implies repeated pilot injection. This can also be accomplished by the repeated pilot injection of small quantities of hypergolic components by a mechanical feed. Repeated pilot injection results in the elimination of the need of means for capturing the combustion gas after firing. Another method of initiating and maintaining the firing by a single means consists in placing a squib at the base of the projectile and firing it by electrical means.

Fig. 3 also illustrates a recoilless feature which is very desirable for specific military applications. The recoilless effect is obtained by providing a passage 31 connecting the combustion chamber with the atmosphere. A valve 32 is inserted where this passage opens into the combustion zone. This valve is so constructed that it will open at a predetermined pressure and allow the release of enough combustion gas to effectively eliminate recoil.

The remaining features of the gun of Fig. 3 are similar to the gun shown in Fig. 1 except for the elimination of line 19 for the return of combustion gas from the barrel to the combustion chamber.

An extensive series of firings of guns embodying the principles of the invention has shown that the many advantages which should be obtained in a liquid fuel gun are realized in the guns of the invention. With a 37 mm. gun embodying the invention, the maximum muzzle velocity obtained amounted to 5450 feet per second with a peak combustion chamber pressure of 24,000 pounds per square inch and a propellant to projectile mass ratio of 5.10. For mass ratios in the range of 1.5, maximum velocities exceeded nitro-cellulose values by as much as twenty percent, at comparable or lower chamber pressures. Other designs operating on similar principles have attained velocities as high as 6500 feet per second at substantially lower peak pressures than is the case for nitro-cellulose powder

The traditional struggle of ballistic personnel to prevent loss of the energy present in the charge and to obtain lower charge to mass ratios for any given muzzle velocity has finally been successfully resolved by the application of this invention. Controlled rate of pressure generation by control over propellant injection as herein described makes this possible.

This invention makes possible many improvements in the mobility and the handling of certain weapons, in the storage and transfer of ammunition, as well as in the design of military vehicles and planes. The elimination of high peak pressures in the combustion chamber permits the reduction of gun weight. Because comparable velocities may be obtained at lower charge to mass ratios, less propellant and chamber volume is required, resulting in shorter gun length. Furthermore, superfluous weight and bulk in the form of cartridge cases and case extractors may be eliminated and a corresponding savings in space afforded. This will completely revolutionize tank design for the shape of the tank turrent is dependent upon the size of the shell that must be manipulated therein. Weight and space considerations are also of great importance in fighter aircraft carrying rapid fire guns. Propellant can now be stored in tanks integrally molded into the design of the plane and not necessarily near the guns. By such an arrangement, a maximum of room may be obtained from the meager available space of aircraft.

This invention will also yield great advantages in ammunition storage and transfer to the gun. On the field the ammunition can be secreted in remote and protected locations and piped to the battle front. Pipeline propellant transfer to the gun itself, rather than by the use of conveyer belts is most conducive to high rates of repetitive fire.

It is to be understood that the forms of the invention, herewith shown and described, are to be taken only as illustrative examples, and that various changes in shape, size, and arrangements of parts may be resorted to without departing from the spirit of the invention and the scope of the claims. Staged injection may be afforded by providing a plurality of spaced injector units along the gun barrel. Propellant-carrying projectiles wherein the injector unit and propellant is housed in a shell behind the projectile are possible. A liquid gun designed on the principles herein described may be utilized in launching guided missiles or man-driven aircraft. The invention may be practiced by using a monopropellant such as nitromethane, hydrogen peroxide, hydrazine, ethylene oxide, acetylene, and methyl acetylene. The energetic decomposition of the monofuel can be initiated by a catalyst, such as permanganate solution in the case of hydrogen peroxide. Although the problem of injecting two liquids will still exist, only a few cubic centimeters of catalyst would be required in such a case and there would be no problem of controlling the injection rate of the catalyst. Other forms of excitation to initiate the explosive decomposition of the monofuel can be provided by electrical means or heat, thereby reducing the injector unit to one injector.

We claim:

1. A liquid fuel gun comprising a combustion chamber, a fuel chamber, a differential area piston transmitting pressure from the combustion chamber to the fuel chamber to effect injection of fuel from the fuel chamber into the combustion chamber, and valve means between the fuel chamber and the combustion chamber normally urged into closed position and actuated into open position by movement of the differential area piston in response to pressure in the combustion chamber.

2. A liquid fuel gun as defined in claim 1 wherein the valve means is provided by contact of the differential area piston with a tapered wall of the fuel chamber.

3. A liquid fuel gun as defined in claim 1 wherein the valve means is positioned in an orifice in the differential area piston providing communication between the fuel chamber and the combustion chamber.

4. A liquid fuel gun comprising a combustion chamber, a fuel chamber, a differential area piston positioned between the fuel chamber and the combustion chamber transmitting pressure from the combustion chamber to the fuel chamber, and pressure means acting on a face of said differential area piston to urge said piston into contact with a tapered wall of the fuel chamber to close communication between the fuel chamber and the combustion chamber at combustion chamber pressures below a predetermined amount.

5. A liquid fuel gun comprising a combustion chamber, a fuel chamber, a differential area piston positioned between the fuel chamber and the combustion chamber transmitting pressure from the combustion chamber to the fuel chamber, said piston having an orifice providing communication between the fuel chamber and the combustion chamber, valve means in said orifice, and pressure means urging said valve means into closed position at combustion chamber pressures below a predetermined amount.

6. A liquid fuel gun as defined in claim 1 including means supplying compressed gas to the combustion chamber to initiate movement of the piston.

7. A liquid fuel gun as defined in claim 1 including valve-controlled means supplying compressed gas to the combustion chamber to initiate movement of the piston.

8. A liquid fuel gun as defined in claim 1 including means to return a portion of the combustion gases from the barrel of the gun to the combustion chamber.

9. A liquid fuel gun as defined in claim 1 including valve-controlled means to return a portion of the combustion gases from the barrel of the gun to the combustion chamber.

10. A liquid fuel gun as defined in claim 1 including means supplying compressed gas to the combustion chamber to initiate movement of the piston and means to return a portion of the combustion gases from the barrel of the gun to the combustion chamber to reactivate the piston.

11. A liquid fuel gun as defined in claim 1 including a fuel reservoir and a check-valve-controlled conduit connecting the fuel reservoir and the fuel chamber.

12. A liquid fuel gun as defined in claim 1 including means for injecting a minor portion of propellant into the combustion chamber to initiate movement of the piston.

13. A liquid fuel gun as defined in claim 1 including means defining a passage connecting the combustion chamber to the atmosphere and valve means in said passage opening at a predetermined combustion chamber pressure.

14. A firearm comprising a breech casing, a barrel affixed to said casing, a combustion chamber formed in said casing and communicating with said barrel, a plurality

of radial bores extending outwardly from said combustion chamber to the periphery of said casing, a plurality of hollow injector pistons having a closed end adjacent said combustion chamber and slidable within said bores, a plurality of hollow bosses fitting said bores and having a circumferentially reduced portion extending within the open end of said pistons, said bosses conducting a predetermined volume of hypergolic reactants to the interior of said pistons, an orifice in the closed end of said pistons, said closed end of said pistons having a large area exposed to said combustion chamber and a smaller area exposed to the said reactants whereby said injector pistons

supply said reactants under progressively increasing pressure and rate of flow to said combustion chamber.

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Steffanus et al.

[11] **4,148,245**

[45] **Apr. 10, 1979**

[54] **FLUID PROPELLANT PROJECTILE FIRING DEVICE**

[75] Inventors: **Robert D. Steffanus; David R. Anderson**, both of Pittsburgh, Pa.

[73] Assignee: **BTGCO**, Coraopolis, Pa.

[21] Appl. No.: **859,868**

[22] Filed: **Dec. 12, 1977**

[51] **Int. Cl.**^{2} **F41F 1/04**

[52] **U.S. Cl.** .... **89/7**; 89/135; 89/137; 89/191 A

[58] **Field of Search** .... 89/7, 191 A, 135, 137

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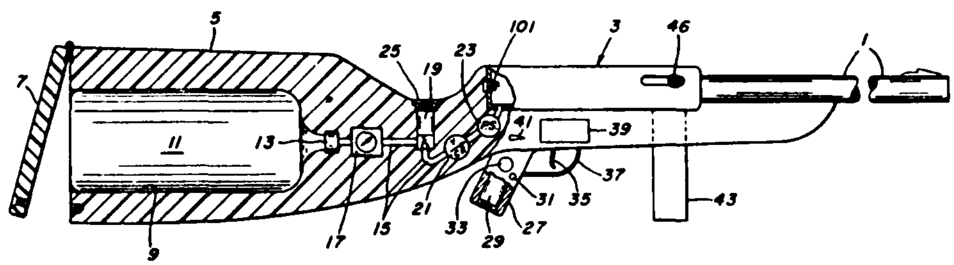
[57] **ABSTRACT**

A projectile firing device utilizing a fluid propellant in which an electronic control responsive to a charging signal, cycling of the bolt in the breechblock to a fully closed position and pressure in the firing chamber below a preset value opens a valve to permit pressurized propellant to flow into the firing chamber and closes the valve and enables electronic triggering circuits when the pressure reaches the preset value. The muzzle velocity of the device may be varied by varying the pressure of the propellant in the firing chamber and the rate of fire in the automatic mode may be adjusted electronically. A spring biased injector finger carried by the bolt urges a projectile from a magazine into the bore of the barrel and retains it there to form a gas tight seal until the propellant is ignited. When no projectiles remain in the magazine, the injector finger prevents the bolt from closing completely and therefore inhibits the electronic control from recharging the firing chamber with propellant.

10 Claims, 5 Drawing Figures



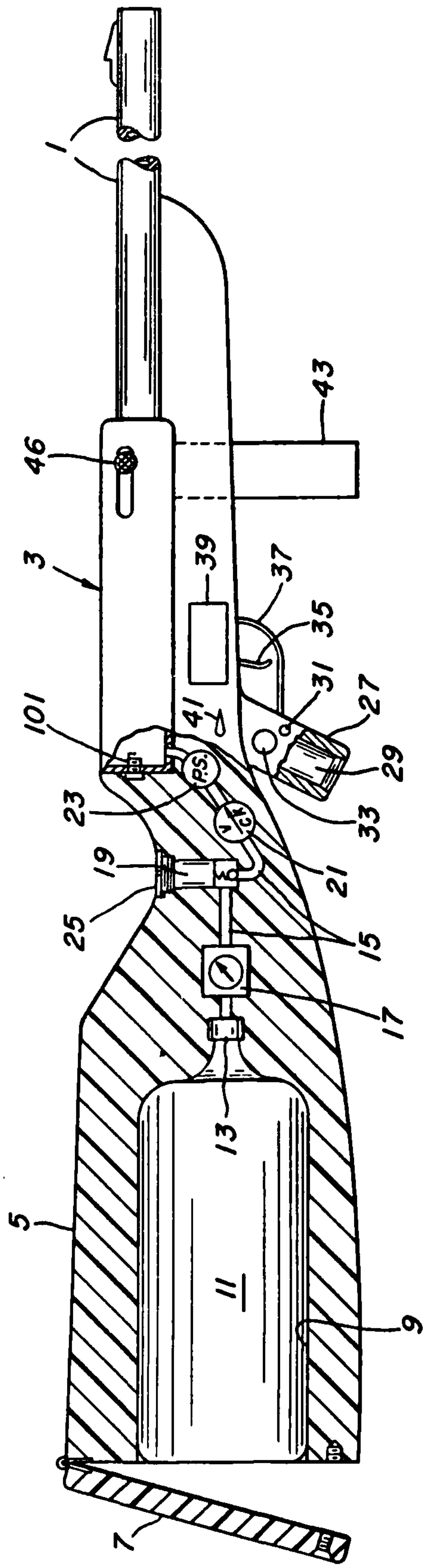


FIG. 1.

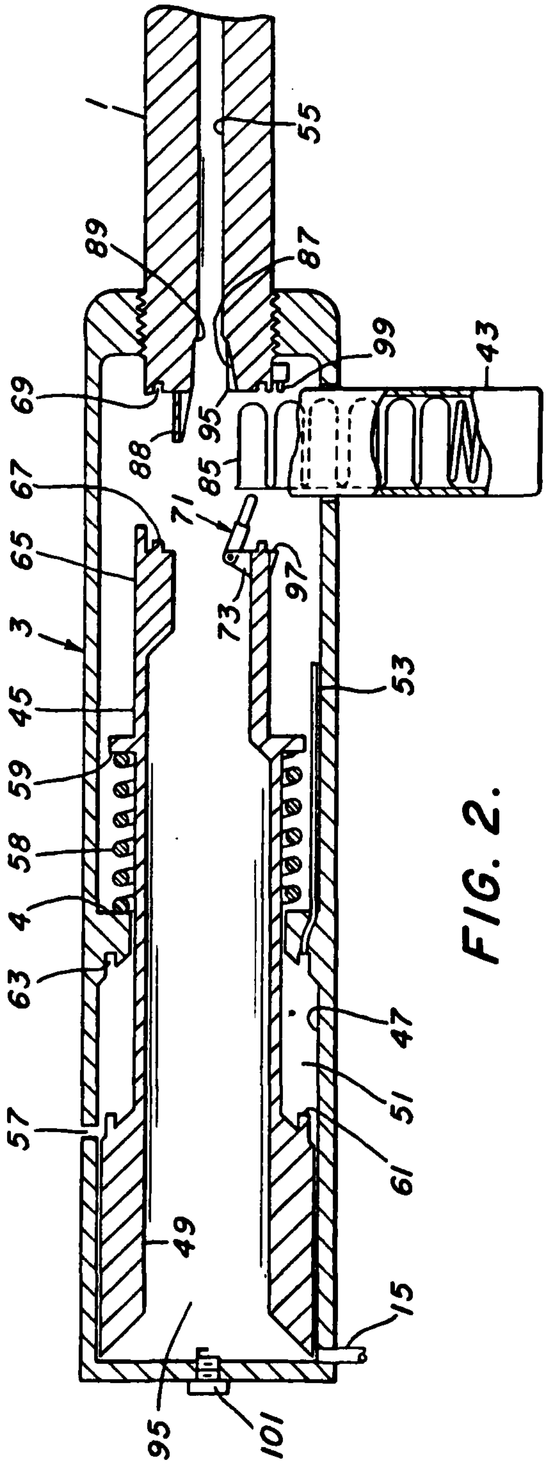


FIG. 2.

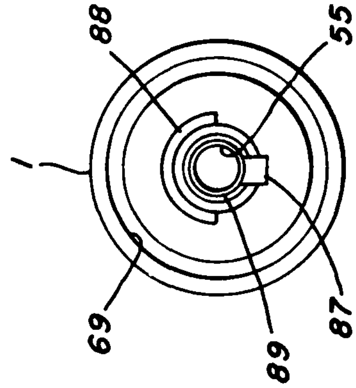


FIG. 3.

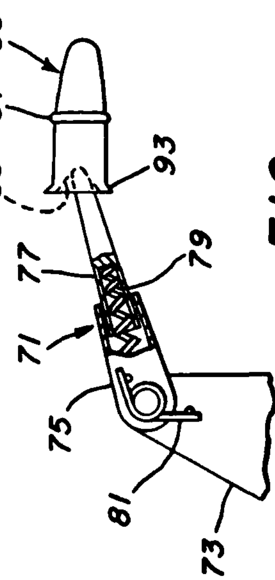


FIG. 4.

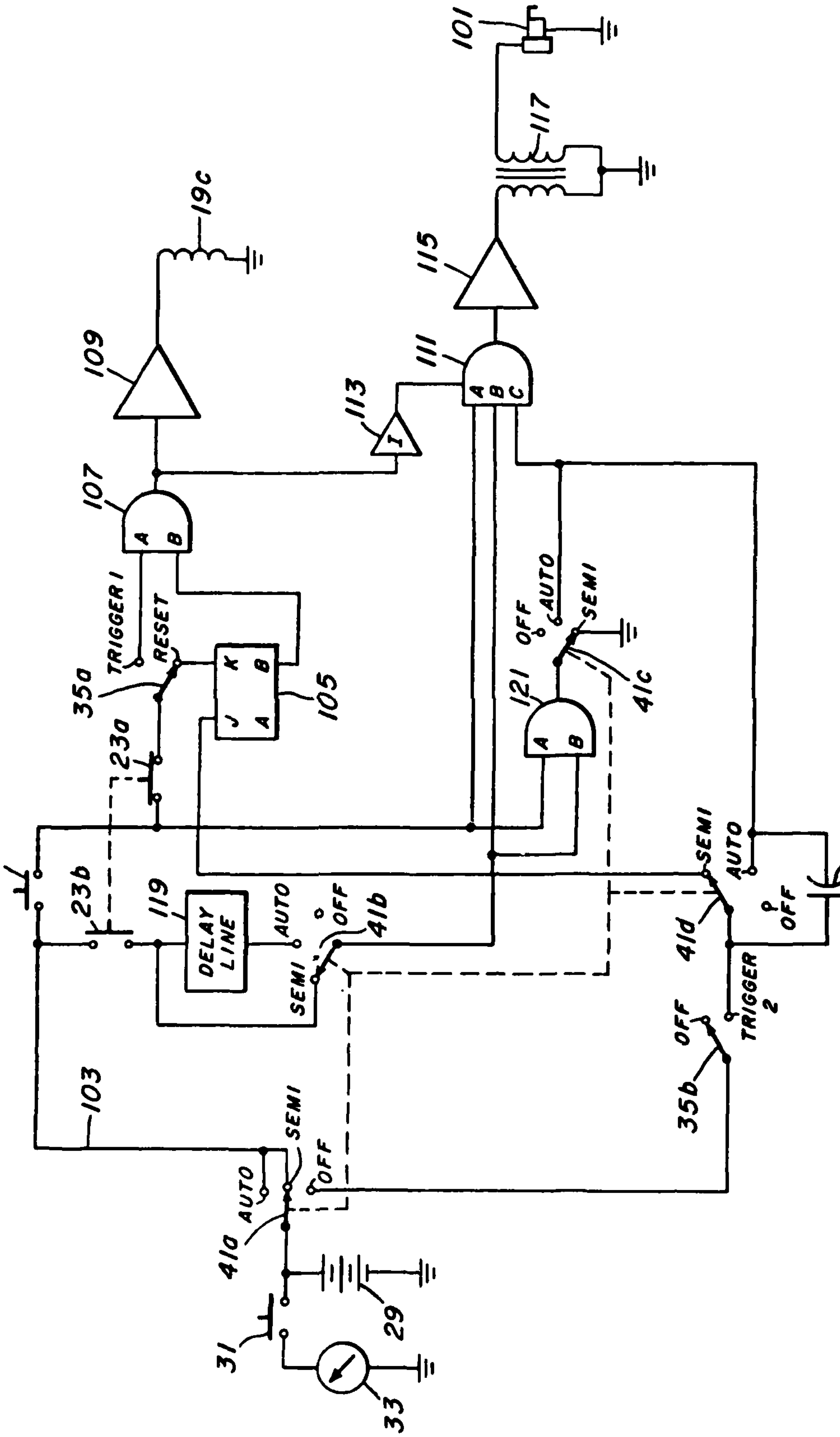

101
117
19c
115
109
111
A B C
113
I
107
A B
TRIGGER 1
RESET
35a
J K
A B
105
OFF
AUTO
SEMI
41c
121
A B
23a
99
23b
119
DELAY LINE
AUTO
OFF
41b
SEMI
SEMI
AUTO
OFF
41d
123
TRIGGER 2
OFF
35b
103
SEMI
AUTO
OFF
41a
29
31
33

FIG. 5.

FLUID PROPELLANT PROJECTILE FIRING DEVICE

BACKGROUND OF THE INVENTION

1. Field of the Invention

The invention relates to devices for firing projectiles and more particularly to such devices utilizing a fluid propellant.

2. Prior Art

Conventional projectile firing weapon systems utilize a measured amount of solid propellant confined in a shell or cartridge casing capped by the projectile and are fired by a percussion cap or primer. The casings, which are normally brass, make such ammunition expensive and heavy to carry and therefore a good deal of effort has been expended lately on developing caseless ammunition in which the solid propellant is attached directly to the projectile without a casing. This arrangement has its own special problems, such as the development of a propellant which is resistant to chipping and cracking when used in automatic weapons and under normal field conditions. Some of these weapons utilize the heat generated by rapid compression of air to ignite the solid propellant while others rely upon impact ignition.

Several types of fluid operated weapons which inherently eliminate the need for a casing have also been proposed. In some, such as those disclosed in U.S. Pat. Nos. 1,383,111 and 3,728,937, a spark or glow plug ignites the fluid propellant. In U.S. Pat. No. 2,947,221 compression ignition of the liquid propellant is utilized to fire the weapon. These prior art weapons for the most part rely upon mechanical devices for charging the fluid propellant into the firing chamber. In U.S. Pat. No. 3,728,937, the operator manually strikes one button to admit butane and another to admit oxygen to the firing chamber after the projectile has been inserted and the bolt closed manually. In U.S. Pat. No. 1,383,111 a pump action is used to charge the firing chamber and in U.S. Pat. No. 3,800,657 the liquid propellant is charged into the firing chamber from dosing chambers by pistons. U.S. Pat. No. 3,255,669 suggests that a gaseous propellant be confined in a detonation chamber which is separated from the barrel and the projectile by a valve until the trigger is pulled and the gas is ignited in order to maintain the gas pressure.

Automatic weapons in which a portion of the gases which drive the bullet down the barrel are vented back to cycle the bolt and reload another cartridge from a magazine are well known. These weapons often provide a semi-automatic mode in which the trigger must be released and resqueezed to fire the next cartridge and a fully automatic mode in which cartridges are loaded and fired continuously as long as the trigger is squeezed. Weapons of this sort are available for both cased and caseless ammunition. While most of these weapons have a fixed rate of fire, it has been suggested that the rate of fire may be varied by adjusting the bleed rate of a pneumatic cylinder connected in the mechanical mechanism.

It is an object of the present invention to provide an improved projectile firing device using a fluid propellant which is simple in design, easily constructed and serviced and is dependable. It is also an object of this invention to provide such a device which is capable of automatic or semi-automatic operation and in which the muzzle velocity and rate of fire are adjustable. Other objects of the invention will be apparent from a reading of the detailed description of a preferred embodiment which follows.

SUMMARY OF THE INVENTION

In accordance with the invention, a projectile firing device includes control means responsive to pressure in a firing chamber below a predetermined value, to a sliding bolt in the breechblock being closed and to a charging signal, for opening a valve to permit the flow of a pressurized fluid propellant into the firing chamber and for closing the valve and enabling electrical triggering means when the pressure reaches the predetermined pressure. The electrical triggering means ignites the propellant to drive a projectile down the barrel of the device. Suitably, the charging signal may be generated by initial movement of the trigger such that the propellant is charged into the firing chamber just prior to ignition and therefore does not have the opportunity to bleed off. The velocity of the projectile may be varied by adjusting the predetermined pressure to which the firing chamber is charged.

In the preferred embodiment of the invention, gases generated by ignition of the propellant are utilized to drive the bolt open as the projectile proceeds down the barrel. As the bolt is returned to the closed position by biasing means, a projectile is fed into the barrel from a magazine. When there are no projectiles remaining in the magazine as the bolt returns to the closed position, means are provided to prevent the control means from operating the valve to recharge the firing chamber with propellant. This means may take the form of a device which prevents the bolt from closing all the way. In the embodiment disclosed, an injector finger pivoted to the bolt is biased outwardly where it engages a recess in the rear of the projectile to urge it from the magazine into the barrel. The injector finger pivots with the movement of the projectile into the barrel to permit the bolt to fully close. However, when no projectiles remain in the magazine, the injector finger remains outwardly biased and prevents full closure of the bolt.

The device may include mode means selectable to a semi-automatic condition to prevent the control means from recharging the firing chamber with propellant following ignition of the propellant until the trigger is released and reactuated and selectable to an automatic condition to permit the control means to operate the valve to repeatedly recharge the firing chamber with propellant and to enable the electrical triggering means to ignite each new charge of propellant as long as the trigger remains actuated. The selectable mode means may include means when in the automatic condition to actuate electrical means to ignite propellant in the firing chamber when the trigger is released and the pressure in the firing chamber is above the preset pressure. This clears the last round out of the firing chamber at the termination of automatic fire. The selectable mode means may also include means when in the automatic condition to generate an adjustable time delay which controls operation of the trigger enabling means to adjust the rate of fire. In the disclosed device, the time delay means is responsive to the pressure in the firing chamber and delays ignition of the propellant for the adjustable time interval after the pressure reaches the preset value.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a side elevation view partially in section of a rifle embodying the invention;

FIG. 2 is a schematic representation of a section through the breechblock of the rifle of FIG. 1;

FIG. 3 is a vertical view of the breech end of the barrel of the rifle of FIG. 1;

FIG. 4 is an enlarged vertical view, partially in section, of an injector finger of the rifle of FIG. 1 showing how it seats in the recess of a projectile; and

FIG. 5 is a schematic diagram of a circuit suitable for operating the rifle of FIG. 1 in accordance with the principles of the invention.

DESCRIPTION OF THE PREFERRED EMBODIMENT

The invention will be described as applied to a rifle as shown in FIG. 1 having a barrel 1, a breechblock 3 and a stock 5. The butt plate 7 of the stock is pivotally mounted to cover a recess 9 in the shoulder portion of the stock which receives a removable pressure bottle 11 containing pressurized fluid propellant for the weapon. The pressure bottle is locked into a receiver 13 and is connected by a conduit 15 through a pressure regulator 17, a solenoid vavle 19, a check valve 21 and pressure switch 23 to the breechblock 3.

The pressure regulator 17 is provided with a gauge which is mounted to give a visual indication of the pressure and, therefore indirectly, the amount of fluid propellant in the pressure bottle 11. The regulator also supplies fluid propellant through the conduit 15 at a preset but adjustable pressure. The solenoid valve 19 controls the flow of pressurized propellant through the conduit 15 as directed by a control circuit to be described below. The solenoid is retained in place in a bore in the stock by a water tight screw cap 25.

The check valve 21, which may suitably be a spring biased ball type, permits flow of pressurized fluid from the pressure bottle 11 to the breechblock 3 but prevents back flow when the weapon is fired. The pressure switch 23 operates two sets of contacts in the control circuit to be discussed below when the pressure in the last portion of the line 15 and therefore in the breechblock 3 is above a preset value. The pressure at which the pressure switch is actuated may be adjusted by a knob on the switch (not shown) which protrudes through the stock 5.

A pistol grip 27 on the stock 5 houses a battery 29 which may be tested by pressing the test button 31 and observing the level of charge on the gauge 33. The trigger 35 is pivotally mounted in front of the pistol grip 27 and is protected by a guard 37. The control circuitry 39 is removably mounted in a compartment in the stock adjacent the trigger 35 and an "OFF — SEMI-AUTO" mode switch 41 is mounted adjacent the compartment for the control circuit 39. A magazine 43 which can hold a supply of projectiles for feeding one at a time into the barrel is inserted through the underside of the stock into the breechblock 3.

FIG. 2 is a schematic representation of a section through the breechblock 3 and the end of the barrel 1. A hollow bolt 45 is received in an axial bore 47 in the breechblock 3 and is slidable between an open position wherein the bolt is moved all the way to the left, as shown in FIG. 2, and a closed position in which the bolt moves to the right to seat against the end of the barrel 1. The end portion 49 of the bolt received in the breechblock 3 is larger in diameter than the remainder of the bolt such that an annular blow back chamber 51 is formed between the bolt and the breechblock 3. A blow back line 53 which is connected to a point (not shown) in the bore 55 in the barrel 1 directs gases generated by ignition of the propellant back to the blow back chamber 51 as the projectile proceeds down the bore 55. These gases then drive the bolt toward the open position (the left as seen in FIG. 2) until the relief port 57 is uncovered and the gases escape to the atmosphere. A large coil spring 58, surrounding the bolt and bearing against a shoulder 4 in the breechblock 3 and an annular flange 59 on the bolt, is compressed as the bolt is driven to the open position by the blow back gases and then biases the bolt toward the closed position as the gases are relieved through the relief port 57. An annular sealing ring 61 on the face of the enlarged end portion 49 of the bolt seats in a mating annular recess 63 in the shoulder 4 of the breechblock as the bolt closes.

The forward end 65 of the bolt 45 is also provided with an annular ring 67 on the face thereof which seats with a mating annular recess 69 in the barrel 1 to form a gas tight seal as the bolt closes. The bolt 45 may also be opened manually by the knurled lever 46 shown in FIG. 1. When the lever is released, the spring 58 drives the bolt to the closed position. The forward end of the bolt also carries an injector finger 71 pivotally mounted on a boss 73. As best seen in FIG. 4, the injector finger 71 comprises two telescoping sections 75 and 77 biased to the extended position by an internal spring 79. The injector finger 71 is biased downward and outward in the path of the closing bolt by a spring 81.

As the bolt is driven in the closing direction, the downward biased injector finger 71 enters the recess 83 in the rear of the top projectile 85 in the magazine 43 and urges the projectile forward and up a relieved portion 87 in the bottom center of the barrel into the bore 55. A hood 88 over the top of the bore assists in seating the projectile in the bore. The bore 55 is countersunk slightly to form a shoulder 89 against which a collar 91 on the projectile seats. The projectile is cast with a flashing 93 on the rear which serves as a seal for the forward end of the firing chamber 95 formed by the bore in the hollow bolt 45, the end of the barrel 1 and the closed end of the breechblock 3. The spring biased injector finger 71 retains the projectile in sealing engagement with the end of the barrel until the weapon is fired. As the bolt 45 closes, a projection 97 on the underside of the bolt which assists the injector finger 71 in inserting the projectile 85 into the bore 55, actuates a bolt closed switch 99 to prepare circuits discussed below for the introduction of the propellant into the firing chamber 95. The pressurized fluid propellant when introduced into the firing chamber 95 through the conduit 15 also bears against the rear of the projectile 85 and retains it in place. Upon actuation of the trigger 35, the pressurized propellant in the firing chamber 95 is ignited by the spark plug 101 through circuitry to be described below. The explosive ignition of the propellant drives the projectile 85 down the bore 55 of the barrel. The flashing 93 on the projectile 85 collapses under the tremendous forces generated, however, the collar 91 on the projectile forms a gas tight seal with the tapered bore 55 and thereby permits the generation of a very high muzzle velocity.

FIG. 5 illustrates a suitable circuit for operation of the disclosed projectile firing device. The battery 29, which may be tested by pressing the push button 31 to give a visual indication on gauge 33 of the state of the battery charge, is connected through the mode switch 41 to a lead 103. The mode switch 41 comprises four ganged three position switches 41 "a" through "d" each

having a "semi" position, and an "auto" position and an inoperative "off" position. The lead **103** is connected, through the normally open contacts of bolt closed switch **99**, a normally closed set of contacts **23a** on pressure switch **23** and a trigger actuated switch **35a**, to either the K input of a J-K flip-flop **105** or one input of AND gate **107**. The switch **99** is closed when the bolt is in the fully closed position. The contacts **23a** of pressure switch **23** are closed when the pressure in the firing chamber **95** is below the preset value and open above that pressure. The switch **35a** is actuated by the trigger **35** and remains in the RESET position as shown in FIG. **5** when the trigger is unactuated but transfers to the TRIGGER 1 position upon initial squeezing of the trigger and remains in this position until the trigger is completely released.

AND gate **107**, when turned on by the TRIGGER 1 output of switch **35a** and the B output of flip-flop **105**, energizes the coil **19c** of solenoid valve **19** through driver **109** and when turned off enables AND gate **111** through inverter **113**. AND gate **111** when turned on generates a firing pulse for spark plug **101** through driver **115** and high voltage transfer **117**. AND gate **111** is turned on by a signal applied to the A input when the bolt switch **99** is closed. a signal applied to the B input through switch **41b** when the pressure in the firing chamber is above the present valve so that the contacts **23b** of pressure switch **23** are closed either directly when switch **41b** is in the SEMI position or through variable DELAY LINE **119** when switch **41b** is in the AUTO position, and by a signal applied to input C either through switches **35b** and **41d** in either the AUTO or SEMI modes, or, alternately in the AUTO mode, by the output of AND gate **121**. Switch **35b** is in the TRIGGER 2 position to apply the required signal only when the trigger **35** is fully depressed. When switch **41d** is in the SEMI position, a pulse is applied to input C of AND **111** through capacitor **123**. AND **121** is turned on by a signal applied to its A input when the bolt switch **99** is closed and a signal applied to the B input from switch **41b**. AND **121** only supplies an activating signal to AND **111** when the switch **41c** is in AUTO.

The above described device operates in the following manner. It will be assumed first that the mode switch **41** is turned to the SEMI position. The operator pulls the lever **46** to slide the bolt **45** rearward and releases it so that the spring **58** drives the bolt toward the closed position. As the bolt **45** moves forward the injector finger **71** slides a projectile **85** from the magazine **43** into the bore **55** in the barrel. As the bolt reaches the fully closed position, the bolt switch **99** is closed which applies a signal to the K input of flip-flop **105** to insure that the flip-flop output is high.

When the operator begins to pull the trigger **35**, switch **35a** transfers to the TRIGGER 1 position thereby turning on AND **107** which in turn energizes solenoid valve **19**. As solenoid valve **19** opens, pressurized propellant flows from the bottle **11** through conduit **15** to the firing chamber **95**. While the firing chamber is being charged with propellant, the inverter **113** disables AND **111** so that the spark plug **101** cannot be energized to ignite the propellant prematurely. When the pressure in the firing chamber **95** reaches the preset value, pressure switch **23** is actuated to open contacts **23a** thereby turning off AND **107** which deenergizes solenoid **19** and enables AND **111**. At the same time the contacts **23b** of the pressure switch close to cause the B

input of AND **111** to go high. The A input is already high due to the signal applied through the bolt closed switch **99**. When the operator depresses the trigger all the way, the switch **35b** is transferred to the TRIGGER 2 position which applies a pulse through capacitor **123** to turn on AND **111** thereby energizing the spark plug **101** and igniting the propellant. At the same time, a signal is applied to the J input of flip-flop **105** to cause the output to go low and prevent turn on of AND **107** as the pressure in the firing chamber decreases and contacts **23a** reclose following discharge of the projectile from the barrel.

As the projectile proceeds down the barrel under the urging of the gases generated by ignition of the propellant, a portion of these gases enter the conduit **53** and are fed back to the blow back chamber **51** where they drive the bolt rearward thereby opening bolt switch **99**. As the bolt reaches the fully open position, the blow back gases are relieved through relief port **57** and the spring **58** drives the bolt **45** forward again to transfer another projectile **85** from the magazine **43** to the bore **55**.

With the mode switch **41** in the SEMI position, the firing chamber cannot be recharged with propellant even though both switch **99** and contacts **23a** reclose, unless the trigger is fully released to return the switch **35a** to the reset position to again set the output of flip-flop **105** high. This ensures that only one projectile may be fired with each squeeze of the trigger in the SEMI mode. However, by releasing and resqueezing the trigger, all of the projectiles in the magazine can be fired one after the other. When no more projectiles **85** remain in the magazine, the downwardly biased injector finger **71** will prevent full closure of the bolt **45** following firing of the last round and therefore the bolt close switch **99** will remain open. With this switch open, it can be seen from the circuit of FIG. **5** that propellant cannot be introduced into the firing chamber. This feature prevents depletion of propellant through the bore in the barrel when it is not plugged with a projectile.

When the mode switch **41** is placed in the AUTO position, the firing chamber **95** is initially charged with propellant in the manner described above as the trigger **35** moves out of the rest position. AND **111** is also enabled by inverter **113** when the firing chamber is fully charged as in the SEMI mode. In addition, the bolt closed switch **99** causes input A of AND **111** to go high. However, input B of AND **111** only goes high a predetermined time interval after the firing chamber **95** is charged and pressure switch contacts **23b** close because switch **41b** now introduces delay line **119** into the circuit. This time delay may be set at any desired interval to vary the rate of fire in the AUTO mode. An adjustment knob can be provided on the delay circuit for this purpose. As the trigger is fully squeezed, switch **35b** goes to TRIGGER 2 to apply a signal to the C input of AND **111** through switch **41d** and the spark plug **101** is fired. The projectile **85** is driven down the barrel and the bolt recycles to load another projectile into the barrel in the same manner as in the SEMI mode.

With the trigger **35** held in the TRIGGER 2 position and the mode switch in AUTO, a continuous high signal is applied to the C input of AND **111**. However, when the bolt switch **99** recloses and AND **107** turns on to recharge the firing chamber with propellant, inverter **113** disables AND **111**. Even when the firing chamber is recharged and pressure switch **23b** closes, AND **111** is not turned on to ignite the propellant until the preset

time delay set by delay line **119** again expires Thus as long as the trigger **35** remains actuated, the projectiles will be propelled down the barrel automatically one after the other at intervals determined by the delay line **119**. When the trigger is released in AUTO, AND **121** will still cause the C input of AND **111** to go high to send a firing signal to the spark plug **101**. However, with the trigger released, the A input to AND **107** will not go high when the bolt closes after firing the last round, and therefore the firing chamber will not be recharged with propellant. This feature assures that the firing chamber does not remain charged with propellant after the trigger is released in the automatic mode. As in the case of the semi-automatic mode, when no more projectiles remain in the magazine as the bolt moves forward, it is prevented from fully closing and actuating the bolt closed switch **99** by the downwardly biased injection finger **71**. If desired, other means could be used to assure that propellant is not introduced into the firing chamber when no projectile is inserted in the bore to form a seal.

Suitable propellants could be either gases or liquids at standard temperature and pressure. The propellant should have a high energy of reaction yet be stable under conditions in which the device would be used. Suggested propellants would include stoichiometric mixtures of oxygen with a hydrocarbon such as methane or a cyclo-alkane, or an unsaturated hydrocarbon such as acetylene, a cyclo-alkane or an arene. Other possible propellants would include nitro derivatives of hydrocarbon compounds such as trinitrotoluene. Where it is desirable to maintain the oxidizer separate from the propellant prior to firing the device, separate pressure bottles with appropriate valving in accordance with the teachings of the invention may be provided.

While the invention is disclosed as applied to a rifle, it is readily apparent that it is adaptable for use in other weapons systems. Some modifications may be desirable in such applications. For instance, in larger devices for use in tanks, ships, airplanes or fixed installations, the propellant source can be separate from the remainder of the device. In some applications it may be desirable that the charging signal, which initiates flow of propellant to the firing chamber, be provided by means independent of initial movement of the trigger. Other variations fully within the teachings of the invention are also possible and the invention is to be given the full scope of the appended claims.

We claim:

1. A projectile firing device comprising:

a barrel;

a breechblock containing a firing chamber mounted on one end of the barrel with the firing chamber in communication with the barrel;

a bolt slidable within the firing chamber of the breechblock between an open position in which a projectile may be inserted into said one end of the barrel and a closed position in which the firing chamber is sealed;

a source of fluid propellant under pressure;

means connecting the source of pressurized fluid propellant with the firing chamber;

valve means in said connecting means for controlling the flow of said pressurized fluid propellant from said source to the firing chamber;

triggering means including a trigger, electrical means responsive to movement of the trigger to electrically ignite the propellant in the firing chamber, and means for enabling said electrical means;

means for generating a charging signal; and

control means responsive to pressure in the firing chamber below a predetermined value, said bolt being in the closed position and said charging signal, to open said valve means to permit flow of the pressurized propellant from said source into the firing chamber, and further responsive to pressure in the firing chamber above said predetermined value to close said valve means and activate said enabling means,

whereby generation of said charging signal with the bolt closed, charges said firing chamber with propellant and actuation of said trigger electrically ignites the propellant to drive the projectile down the barrel.

2. The apparatus of claim 1 wherein said charging signal generating means is connected to said trigger and generates said charging signal upon initial movement of the trigger.

3. The device of claim 1 including adjustable pressure regulating means in said connecting means for regulating the pressure of the propellant delivered to the firing chamber whereby the mass of the charge of propellant introduced into the firing chamber and therefore the velocity attained by the projectile is readily adjustable.

4. The device of claim 1 including:

a magazine connected to the breechblock for storing a plurality of projectiles;

means utilizing the gases generated by ignition of the propellant for driving the bolt toward said open position as the projectile proceeds down the barrel;

biasing means for returning said bolt to the closed position; and

means connected to said bolt for transferring a projectile from said magazine into said one end of the barrel as said bolt is driven from the open position to said closed position and for preventing said control means from opening said valve means to recharge the firing chamber with propellant when no projectiles remain in the magazine as the bolt is driven by the biasing means toward the closed position whereby a projectile is automatically inserted into said one end of the barrel following firing of the device and further transfer of propellant to the firing chamber is inhibited when no projectiles remain in the magazine.

5. The device of claim 4 wherein the means for transferring projectiles from the magazine to the barrel and for preventing the control means from transferring propellant to the firing chamber when no projectiles remain in the magazine include means for preventing said bolt from reaching the fully closed position when no projectiles remain in the magazine.

6. The device of claim 5 wherein said projectiles are provided with a recess in the rear portion thereof and wherein said means for transferring said projectiles and for preventing the bolt from reaching the fully closed position when no projectiles remain in the magazine comprises a finger pivotally mounted to the bolt and biased outwardly to engage the recess in a projectile in the magazine to drive the same along inclined guides into said one end of the barrel, said outwardly biased finger pivoting with the movement of the projectile to permit closure of the bolt but remaining outwardly biased to prevent closure of the bolt when no projectiles

remain in the magazine as said bolt is driven toward the closed position.

7. The device of claim 4 including mode means selectable to a semi-automatic condition to prevent the control means from opening the valve means to recharge the firing chamber with propellant following ignition of the propellant until said trigger is released and reactuated, and selectable to an automatic condition to permit said control means to operate the valve means to repeatedly recharge said firing chamber with propellant and to enable the electrical means to ignite the new charge of propellant as long as the trigger remains actuated.

8. The device of claim 7 wherein said selectable mode means includes means when in said automatic condition to actuate said electrical means to ignite propellant in said firing chamber when the trigger is released and the pressure in said firing chamber is above said preset value whereby no unignited charge of propellant remains in the firing chamber upon release of the trigger.

9. The device of claim 7 wherein said selectable mode means includes means when in said automatic condition to generate and adjustable time delay and wherein said enabling means is responsive to the time delay to delay ignition of the propellant by the electrical means for said adjustable time delay whereby the rate of fire in said automatic mode is adjustable.

10. The device of claim 9 wherein said time delay means is responsive to the pressure in the firing chamber and delays ignition of the propellant the adjustable time interval after said pressure reaches said preset value.

* * * * *

FOREIGN FIRM PATENTS

Patent Number: 3,576,103
Author: Peter B. Klein, Ilford, Essex, England
Title: Firing of a Fuel or a Monofuel
Date: April 27, 1971

Patent Number: 4,099,445
Author: Dietrich Singelmann, Ottobrunn, Germany; Heinrich Strobl, Munich, Germany; German Munding, Bad Friedrichshall, Germany
Title: Pressure Differential Piston-Combustion Chamber System
Date: July 11, 1978

Patent Number: 4,100,836
Author: Heinrich Hoffman, Grobenzell, Germany
Title: Combustion Chamber System for the Production of Propelling Gases
Date: July 18, 1978

United States Patent

[11] 3,576,103

[72] Inventor Peter B. Kahn
Ilford, Essex, England
[21] Appl. No. 814,891
[22] Filed Apr. 3, 1969
[45] Patented Apr. 27, 1971
[73] Assignee The Plessey Company Limited
Ilford, England
[32] Priority Apr. 4, 1968, Feb. 27, 1969
[33] Great Britain
[31] 16216/68 and 10476/69

[54] **FIRING OF A FUEL OR A MONOFUEL**
6 Claims, 2 Drawing Figs.

[52] U.S. Cl. 60/26.1, 89/7
[51] Int. Cl. F01b 29/08
[50] Field of Search 60/26.1; 89/7

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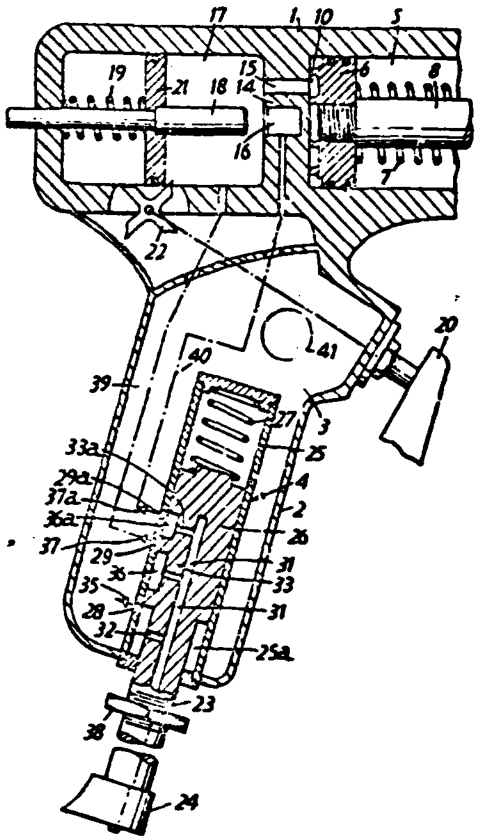
Primary Examiner—Wendell E. Burns
Attorney—Blum, Moscovitz, Friedman & Kaplan

ABSTRACT: To initiate liquid-fuel combustion or monofuel decomposition, and particularly to operate an impact cylinder by a fuel without requiring a spark or hot point, part of the fuel for each stroke is injected into a firing breech containing a gas and sealingly cooperating with a firing pin which when released by a trigger fires this fuel by compression of the gas in the breech to reach firing pressure and temperature, the resultant pressure increase being utilized for opening communication from the breech to a main reaction chamber into which the remainder of the fuel has been injected and also for recocking the firing pin.



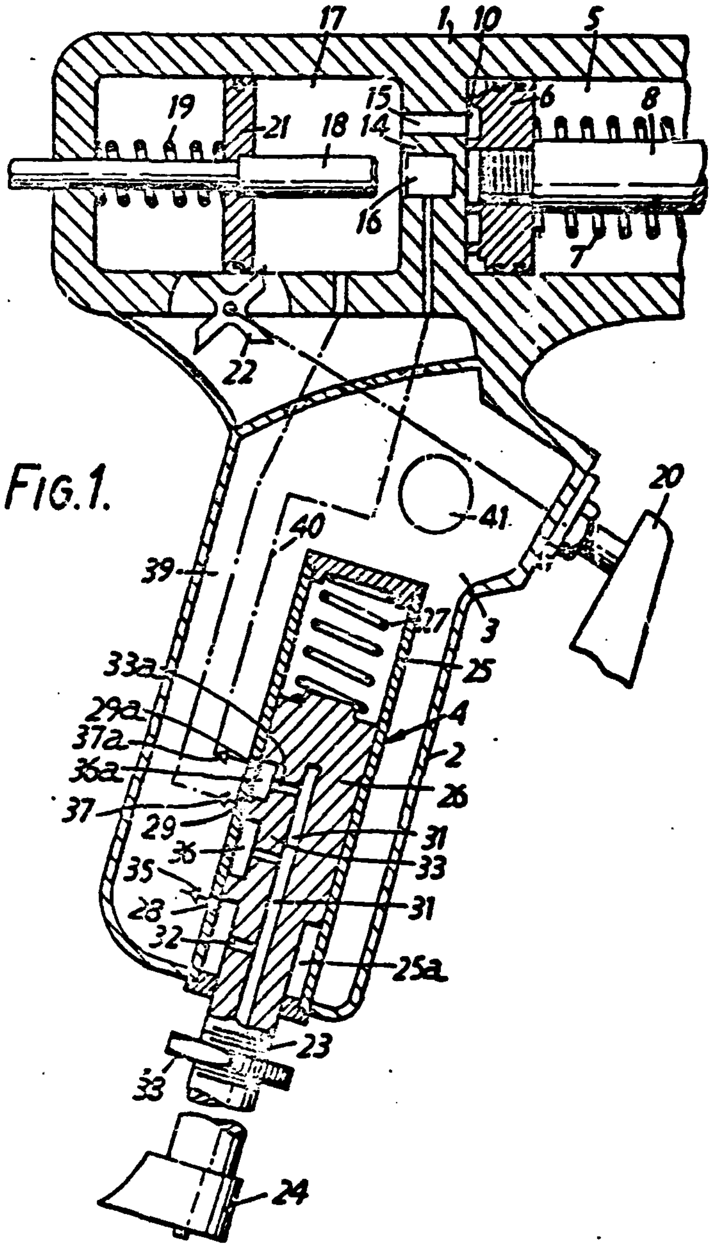

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FIG. 1.

FIG. 3.

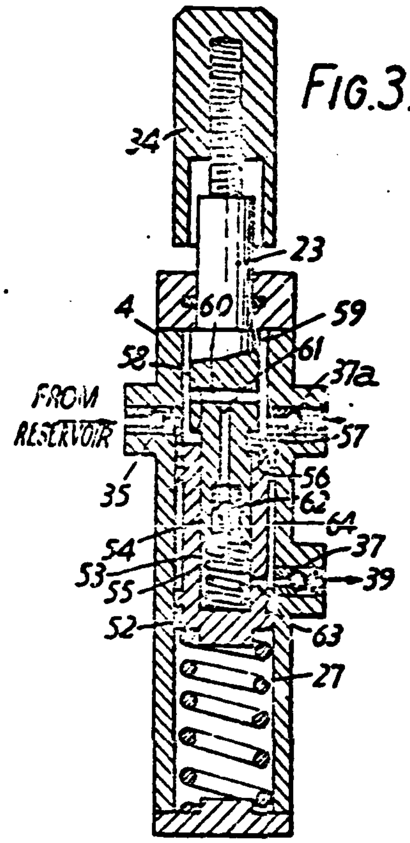


FIG. 2.

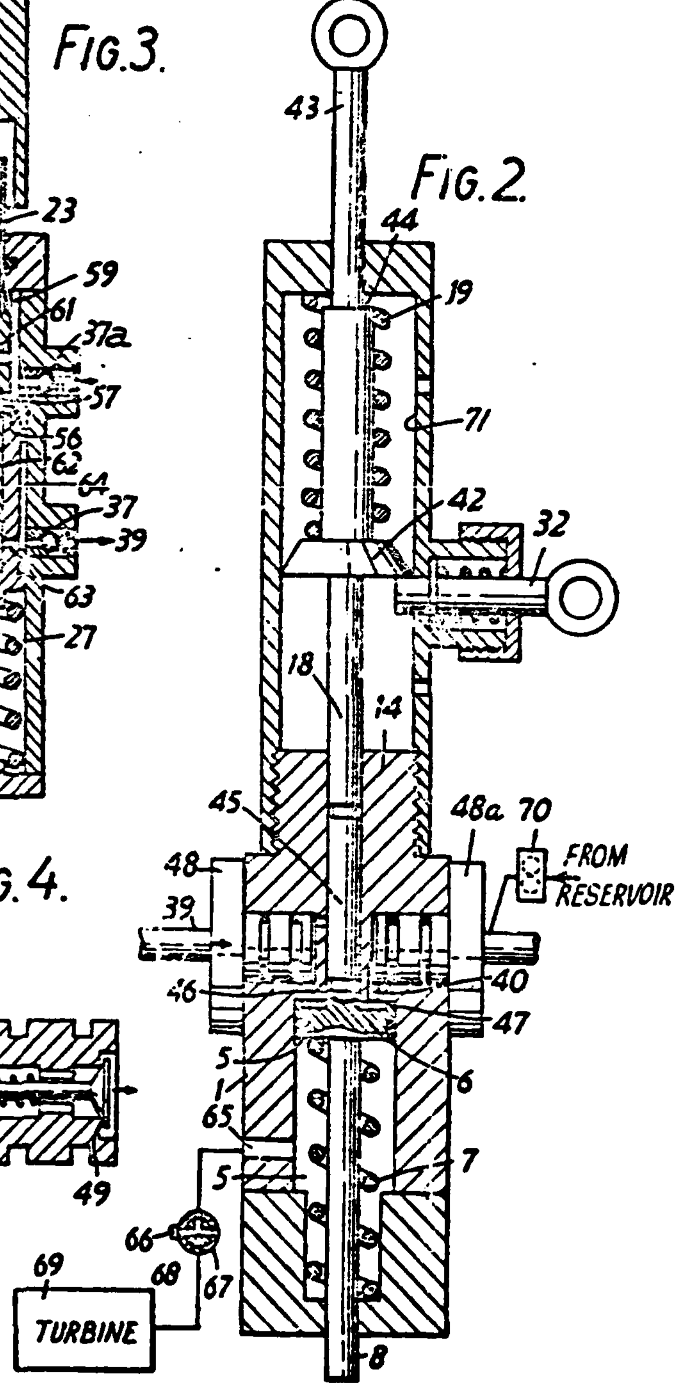
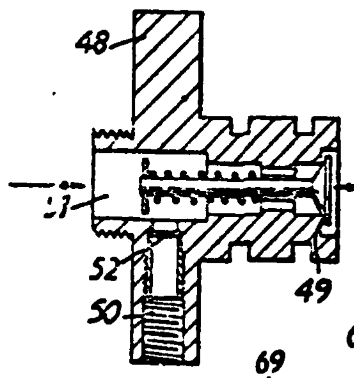


FIG. 4.



FIRING OF A FUEL OR A MONOFUEL

This invention relates to the initiation of a chemical reaction in which a fuel, which may be a monofuel, is utilized to produce a hot gas mixture under pressure. Such reaction may be the combustion of an ordinary fuel, particularly a liquid fuel, or the decomposition of a monofuel, and hereinafter the term fuel, unless the context otherwise requires, is intended to include monofuel. A monofuel, also known as a monopropellant (a term used for example in U.S. Pat. No. 2,947,221), is a substance capable of developing heat by an internal reaction not requiring the presence of oxygen, and the below-mentioned isopropyl nitrate is one example of a monofuel or a monopropellant. In both cases the initiation of the reaction, also referred to as the firing of the fuel, requires the temperature of the fuel to be raised, at least locally, to a predetermined minimum temperature also referred to as the firing point, and the present invention has for an object to provide an improved system and apparatus for achieving this without the need of providing either an electric spark or a solid body raised to incandescent temperature. A further object is to provide a firing device for a fuel-and-gas mixture, in which on the one hand firing is effected by adiabatic compression of a gas to which the fuel has been added while on the other hand the pressure rise subsequent to the firing is kept relatively low so as to avoid the need of an excessively heavy construction of the device.

According to a broad aspect of the invention, which can be applied both to the firing of a monofuel in the presence of a gas which may be inert and to the firing of a mixture of other fuel with air or other oxygen-containing gas, a breech is charged with the fuel in the presence of the gas, and the fuel-and-gas mixture in the breech is then compressed, to establish spontaneous-firing conditions, by a spring-loaded piston element, hereinafter called a firing pin, released by trigger action and free to be moved back after the firing by the increased breech pressure resulting from the firing, and preferably arranged to be recocked by this return movement. Thus the volume increase of the firing chamber after ignition is not, as in a diesel engine, limited by an element, such as a piston connected to a crankshaft, whose movement is predetermined, in practice according to a steady cycle, since the firing pin will give way with very little inertia to the pressure resulting from the firing, thereby avoiding an excessive sudden increase in pressure.

In a more specific aspect of the present invention a metered quantity of a liquid monofuel, for example isopropyl nitrate is, in a cocking operation, transferred from a reservoir into a breech and the monofuel in the breech is then fired by compressing the gas in the breech by the rapid movement of a spring-loaded piston or plunger which may be referred to as firing pin, when the firing pin is released by trigger action from a cocked position, the firing pin being, immediately after firing, forced back and thus cocked for the next firing operation by the breech pressure of the decomposing monofuel. The breech is further provided with a port which, immediately after the firing, establishes communication between the breech and a further portion of the reaction chamber. To achieve this, the return movement of the firing pin may open the breech to a main portion of the reaction chamber, in which before the firing the mixture of gas and fuel or monofuel is under a pressure substantially lower than the firing pressure. The increase in pressure and temperature due to the admission of the fired gases from the breech then causes the mixture in said main part of the reaction chamber to be also fired. The power of the decomposing monofuel may be used to operate an impact piston which operates against a thrust spring, by which the piston is, after each firing, returned to its starting position, an atmospheric vent port being preferably provided to vent the decomposition chamber at the end of each operating stroke. Charging or priming of the reaction chamber, which in this case may also be called the decomposition chamber, with liquid monofuel from a monofuel reservoir is preferably effected by manual forward movement and subsequent spring-actuated return of a pump piston in a pump cylinder communicating through nonreturn valves with the reservoir and the decomposition chamber. In order to permit ready adjustment of the quantity of monofuel injected to match the desired impact, an adjustment end stop for the piston stroke is preferably combined with the priming pump, whose piston is preferably arranged to aspire monofuel from the reservoir during its manually effected inward stroke while a return spring is compressed and to expel the same amount of monofuel from the priming-pump cylinder during the spring-operated return stroke via the passage in the piston which contains a nonreturn valve and which at the end of the return stroke communicates with an atmospheric port so as to prevent reliably the transmission of any pressure from the decomposition chamber past the nonreturn valves in the delivery line and in the reservoir line to the monofuel reservoir.

Alternatively the reaction chamber may, if desired, be arranged to deliver gas to a gas turbine, more particularly to a starter gas turbine. In that case monofuel is after the firing continued to be fed to the reaction chamber at a steady rate for as long as the starter turbine is required to be operated.

In order that the invention may be more readily understood, a number of examples will now be described with reference to the accompanying drawings, in which:

FIG. 1 illustrates one form of a firing system for monofuel shown in axial section, together with a single-stroke piston intended to be operated by the decomposition gases, and with a charging and/or priming pump,

FIG. 2 is an axial section of another form of monofuel-operated piston device constructed according to the invention,

FIG. 3 is an axial section of a priming pump for use therewith, and

FIG. 4 is an axial section, drawn to a larger scale, of the inlet valve provided with back pressure protection means.

Referring now first to FIG. 1, the illustrated device comprises a cylinder barrel 1 having a cylinder bore 5 in which an impact or working piston 6 having a piston rod 8 is slidably movable from its illustrated normal position against a return spring 7. In use the piston is actuated by monofuel-decomposition gas produced in a cylindrical reaction chamber 17 coaxial with, but separated by a partition 14 from, the cylinder bore 5, decomposition gas being admitted from the reaction chamber to the end of the cylinder bore 5 by a passage 15 in the partition 14. The reaction chamber 17 is extended in the axial direction of the barrel 1 by a breech 16 of smaller diameter, and arranged slidably in the chamber 17 is a precompressor piston 21, from which a cylindrical plunger 18, hereinafter referred to as a firing pin, projects towards the breech 16, in alignment with the latter, so as to be movable into the breech, in which it is a sealing fit. The precompressor piston 21 is illustrated in its cocked position, in which a helical firing spring 19 is axially compressed, and in which the piston 21 is retained by a detent or sear 22, which is releasable by a trigger lever 20 at this time the reaction chamber 17 and the breech 16 are filled with a gaseous fluid, which may be air or the gaseous products of a preceding operation. The cocking and trigger means may be of any known or suitable construction, for example be as described in U.S. Pat. No. 3,366,058. When it is intended to operate the working piston 6 by monofuel-decomposition gas, a suitable quantity of liquid monofuel, for example of isopropyl nitrate, is fed from the reservoir 3 into the reaction chamber 17 by a priming pump 4. This pump is arranged to meter, in a first part of its operative stroke, a preselected quantity of monofuel into the reaction chamber 17 proper by a line 39, and to deliver, near the end of its operative stroke, a fixed small further quantity of monofuel into the breech 16 by a second line 40. When now the precompressor piston 21 is released upon actuation of the trigger 20, the helical spring 19 moves the precompressor piston rapidly forward to increase the pressure of the gas contained in the reaction chamber 17 and, after a suitably increased pressure has been reached in

this chamber, the firing pin 18 enters the breech 16, thereby sealing a quantity of the thus precompressed gas in the breech 16, whose residual length is considerably less than the remaining length of the reaction chamber 17. Further movement of the precompressor piston 21 and its firing pin 18 will therefore cause, during the following part of the movement of piston 21, the pressure in the breech 16 to rise much more rapidly than that in the chamber 17. Owing to the small cross-sectional area of the breech 16 compared to that of the reaction chamber 17, this final part of the forward movement of the piston structure 21, 18, which by this time has acquired a considerable kinetic energy, will cause the pressure and temperature in the breech 16 to rise rapidly to reach the firing point. The resultant decomposition of monofuel cause the pressure in the breech to rise further very sharply, and as a result the firing pin is thrown back at a high velocity to acquire an energy sufficient to return, assisted by the pressure in the reaction chamber, the precompressor piston 21 to its illustrated position, where it is once more retained by the detent 22. As soon as, during this return movement, the firing pin 18 leaves the breech 16, the decomposition gases from the breech enter the main reaction chamber 17, where the resulting increase in pressure and temperature initiates decomposition of the monofuel contained in that chamber. A high pressure will thus be created in the reaction chamber 17, though this pressure will not be as high as that momentarily developed in the breech, because the initial compression of the gases in chamber 17 is lower than that reached in the breech at the moment of spontaneous firing. This reaction-chamber pressure acts, through a passage 15, on the area of an annular recess 10 of the working piston 6, and when the pressure acting on this area is high enough to overcome the force of the return spring 7, the impact or working piston 6 begins to move away from the partition 14 which separates the cylinder 5 from the reaction chamber 17, thus allowing the reaction-chamber pressure to reach the whole area of the working piston 6. This piston is thus given a high rate of acceleration to reach a high speed which may be utilized in an impact tool in any known or convenient manner.

The priming pump 4 comprises a piston rod 23 equipped with a stepped pump piston 26. The latter slides in a pump cylinder 25 and is urged by a bias spring 27 towards the illustrated end position. When it is desired to prime the system, the pump piston 26 is moved against the bias spring 27 by pressing a knob 24 mounted on the end of the piston rod 23. This inward stroke of the pump piston 26 is limited by abutment of an adjustable stop nut 38 against the end of the pump cylinder 25, adjustment of the knob serving to determine the amount of monofuel injected at each reciprocation in accordance with the momentary requirements of the system. The pump cylinder 25 has three apertures or ports 28, 29 and 29*a*, of which the first-mentioned aperture 28 communicates with the monofuel reservoir 3 through a nonreturn valve 35, while the apertures 29 and 29*a* lead respectively through line 39 to the main reaction chamber 17 and through line 40 to the firing breech 16, each of the lines 39 and 40 being fitted with a nonreturn valve 37 and 37*a* respectively. A longitudinal passage 31 is provided in the pump piston 26 and the piston rod 23 and communicates with three radial ports 32, 33 and 33*a*. The first-mentioned port 32 permanently communicates with the first-mentioned pump-cylinder port 28 through the end portion 25*a* of the bore of pump cylinder 25, while the other two ports 33 and 33*a* of the piston 26 respectively communicate with longitudinal channels 36 and 36*a* at the circumference of the pump piston 26 in such manner that, when the pump piston 26 returns to its illustrated position after the knob 24 has been depressed, channel 36 first allows monofuel displaced by the piston from the said end chamber 25*a* of the cylinder 25 to flow to the main decomposition chamber 17 while, from a predetermined point shortly before the end of the return stroke of the pump piston the channel 36 leaves the second cylinder port 29 but the other channel 36*a* begins to communicate with the third cylinder port 29*a* thus ensuring that, irrespective of the amount of work required to be done by the decomposition products. The firing breech 16 is always fed with a metered quantity of monofuel suitable to ensure optimum firing conditions, while variation of the power output of the device is achieved by varying the amount of monofuel fed to the main reaction chamber 17.

It will be readily appreciated that, while the invention has been described as applied to an impact piston, the same principle of operation can also be applied to other uses, for example for initiating the operation of a continuously operating device such as a starter gas turbine. For this purpose the piston 6 may be constructed as, or replaced by, a pressurizing valve which remains closed until the pressure in the reaction chamber 17 reaches a predetermined value, and an additional fuel pump, suitable to provide a continuous steady supply of monofuel to the reaction chamber 17, is provided and arranged to commence operation when, or shortly before the piston 21 and firing pin 18 is released to initiate monofuel decomposition in the breech 26.

When it is required to replenish the monofuel in the reservoir 3, this can be done by opening a lateral cover 41 provided for the purpose. Finally it will be appreciated that, while the invention is mainly intended for use with monofuel such as isopropyl nitrate, it is also capable of being operated with fuels requiring oxygen for combustion, for example with petrol or with diesel oil, provided that in that case arrangements are made to ensure for each operation the presence of combustion-sustaining gas, generally air, in the reaction chamber 17 at a suitable quantitative ratio to the monofuel.

Another embodiment of the invention is illustrated in FIGS. 2 to 4, in which the same reference numbers as in FIG. 1 have been employed for parts performing the same functions.

Referring now to FIG. 2, and concentrating on the features which differ from those of FIG. 1, it will be noticed that the firing pin 18, instead of being attached to a precompression piston as that shown at 21 in FIG. 1, is attached to a guide rod 43 provided with a spring abutment head 42, on which the spring 19 acts, and which is freely movable in a vented bore 71. The movement of the head 42 is so limited by a shoulder 44 on its guide rod 43 that the end of the firing pin 18 remains permanently engaged in a breech 45 which latter, like the breech 16 of FIG. 1, is formed in the partition 14 that forms the end wall of the working cylinder 5; but in contrast to the construction of FIG. 1, the breech 45 is formed as a through bore. As a means for retaining the firing pin in the cocked position, a simple spring-loaded trigger pin 32 is shown, which however may, if desired, be equipped with means which ensure its reengagement as soon as the firing pin 18 and spring abutment head 42 return to the illustrated position after firing.

The guide rod 43 is adapted, as shown, to be manually withdrawn to enable the firing pin 18 to be cocked manually when it has been released in the absence of a charge. The spring-loaded piston 6 is formed with a central boss 46 which, when the piston is held in its illustrated end position by the spring 7, seals the exit from the through-bore breech 45 into the cylinder bore 5, which forms the reaction chamber while a peripheral collar 47 of the piston 6 keeps the end surface of the piston slightly spaced from the partition 14 to form an annular chamber 9 surrounding the boss 46. The passage 4 through which the variable greater portion of the monofuel is supplied from the priming pump 4 for the operation of the working piston 6, is arranged to lead into this annular chamber 9 via an inlet check valve 48*a* and a similar inlet check valve 48 is interposed in the passage 39 which feeds an invariable small quantity of monofuel into the breech 45 for firing purposes. As will be seen in FIG. 4, the housing of the inlet valve 48 is provided, to the back of its valve seat 49, with a cross bore 50 intersecting the flow passage 51 leading to the valve seat 49, and this cross-bore 50 is normally closed by a burst disc 52. Should for any reason the valve fail to prevent back pressure from the firing breech 45 or from the pressurized end of the cylinder bore 5 from reaching the passage 51, which isolated from the monofuel reservoir by one of the deliver

valves 37 and 37*a* of the priming pump 4, the resultant pressure buildup in the passage 51 will burst the disc 52, thus venting the passage 51 to a point at low pressure and avoiding any risk of transmission of firing pressure back to the monofuel reservoir.

Referring now to the construction of the priming pump illustrated in FIG. 3, it will be noticed that this pump has been modified from that shown in FIG. 1. Thus the actuating knob 34 of the construction of FIG. 3 combines the functions of the actuating knob 24 and of the adjuster nut 38 of FIG. 1, and instead of arranging for a single pump piston 26 to feed in succession first a variable quantity of monofuel to the main reaction chamber and then a smaller, fixed quantity to the breech, the single piston 26 has been replaced by a main pump piston 52, which serves for the supply of monofuel by a line 40 to the annular chamber 9 surrounding the boss 46 of the working piston 6, and this main piston 52 has a coaxial bore 53, in which an auxiliary piston 54 is movable relative to the main piston 52 between a normal position, to which the auxiliary piston is urged by a spring 55, and in which the auxiliary piston 54 is arrested by engagement of a pin 56, projecting from the main piston into a groove 57 of the auxiliary piston, with the end of that groove, and a second position, in which a shoulder 58 of the piston rod 23 terminates the inward movement of the auxiliary piston 54 into the coaxial bore 53. Fuel from the monofuel reservoir is admitted by the inlet valve 35 to an annular chamber 59 which surrounds the pump-piston rod 23 and which communicates, via intersecting bores 60, 61 and a check valve 62, with the bore 53 containing the auxiliary piston 54 and, via a bore 63 and a longitudinal groove 64 in the main piston 52, with the delivery valve 37 which, via line 39, leads to the breech 45. The preloading of the spring 27, which holds the main pump piston 52 in its normal position, is so chosen as to retain when, by pressing the actuating knob 34, the piston rod 23 is moved, the main piston 52 until the auxiliary piston 54 has completed its full permitted stoke thus delivering a predetermined quantity of monofuel to the breech chamber 45. Continued inward movement of the knob 34 then causes the main piston 52 to move jointly with the continued forward movement of the auxiliary piston 54, thereby increasing the capacity of the annular chamber 59 surrounding the piston rod 23 and thus aspiring monofuel from the reservoir through the inlet valve 35. When the knob 34 is now released, the spring 27 will return the main pump piston 52, and the spring 55 will at the same time return the auxiliary piston 54 to its original position relative to the main piston thus causing initially monofuel from the annular chamber 59 to be transferred to the bore 53 constituting the auxiliary cylinder in which the auxiliary piston works, and when this auxiliary cylinder has been fully charged, continued return movement of the main piston 52 will cause the residue of the aspired monofuel to be expelled via delivery valve 37*a* and line 40 to the annular chamber 9 which constitutes the reaction chamber in the main cylinder bore 5 of the barrel 1. It will be observed that in this manner the charging of the breech is effected during the depression of the knob 34 while the annular chamber 9 is charged during the return movement of the knob 34 and piston rod 23.

When the auxiliary piston 54 has returned to its initial position relative to the main pump piston 52 while the latter continues its return movement, some of the fuel expelled from the annular chamber 59 might flow via passages 60, 61, valves 62, cylinder bore 53, and valve 37 into the breech chamber 45, and to prevent this the pressure drop in the two series-connected nonreturn valves 62 and 37 is arranged to be appreciably greater than the pressure drop in the single nonreturn valve 37*a* provided in the line to the main reaction chamber 9.

When, after the priming pump 4 has been operated, the trigger pin 32 is pulled, the cocking spring 19 is freed to propel the firing pin 18 rapidly into the breech 45 to compress the gas contained therein until the pressure and temperature in the breech causes the monofuel in the breech to decompose spontaneously. The resulting pressure rise in the breech 45 n only moves the firing pin back, cocking it for a fresh firi operation, but also acts on the boss 46 of the working pis to move the boss out of the breech 45, thus establishing munication of the breech with the main reaction chamber so as to fire the main quantity of monofuel which has been f to the reaction chamber via passage 40. Moreover the sure of the decomposition gases will now act on the whole of the piston 6 as distinct from acting only on the area responding to the cross section of the boss 46 as it was prior the establishing of communication between the breech 45 ar the annular chamber 9.

The main cylinder 5 is formed with an exhaust po which is exposed when the piston 6 has moved a predete mined distance from its illustrated normal position. This e haust port 65 will open to atmosphere, as shown, by a mospheric port 66 when the piston 6 is to work as an in piston or a reciprocating piston and constitutes the outp member, but alternatively, as indicated by the provision of three-way cock 67, the port 65 may be connected to an o line 68 at which a continuous supply of decompositio may be required, for example when as shown the line 68 to a gas turbine 69. In order to provide such continuous g supply, the monofuel supply line 40 leading to the workir chamber 9 will, after firing, be connected to a contir supply source 70 of monofuel, which may be of a constru described in U.S. Pat. No. 2,874,764 or in U.S. Pat. N 3,146,591 and may, as in these cases, include a gear pum driven by the turbine. The pressure of the decompo gases will then, as long as the supply of monofuel conti hold the piston 6 in a position in which it allows the passage the gases through outlet 65.

I claim:

1. A device for firing a mixture of a liquid fuel as defin the specification and a gas, which comprises a body incl a reaction chamber and a breech bore extending from th reaction chamber and having a substantially smaller diamet than the reaction chamber, said breech bore having a cyl cal portion, first closure means movable longitudinally breech bore between a closed position in which said first cl sure means isolates the breech bore from the reactic chamber and an open position in which it permits free munication between the breech bore and the rea chamber, spring means urging said first closure means to sa closed position, second closure means closing the other end the breech bore, a firing pin guided in said body for move along the axis of said breech bore between a first positio a second position said firing pin constituting one of saic and second closure means and including a cylindrical port which is a sealing fit in said cylindrical bore portion and movable therein towards the other of said closure mea compress, when rapidly moved from said first position t second position gaseous fluid in said breech bore sufficient to ensure firing of such mixture in the breech by adiabat compression, spring means urging said firing pin to second position, detent means for releasably holding sa fi ing pin in said first position, detent-release means operab release said detent means and charging means associated wi said body and operable to supply fuel to said reaction cha and, prior to each release of said detent means, to said b bore, said body also including conduction means for re gases from said reaction chamber to permit such gases produce mechanical power.

2. A device as claimed in claim 1, wherein the cha means include a single-stoke priming pump arranged to s fuel to both the breech and the reaction chamber in i dividually metered quantities.

3. A device as claimed in claim 2, wherein the pr pump includes means for adjusting the quantity of fue plied to the reaction chamber without affecting the quan fuel supplied to the breech.

4. A device as claimed in claim 1, wherein said bod i cludes a monofuel reservoir associated with said ch means.

5. A device as claimed in claim 1, for use in connection with a gas turbine, wherein the charging means include means operable, after the release of the detent means, to direct a continuous supply of fuel to the reaction chamber, the device including a pressurizing valve rendering said conduction means ineffective until the pressure in the reaction chamber reaches a predetermined valve.

6. A device as claimed in claim 1 wherein the breech bore is a socket bore closed at its end remote from the reaction chamber, and which includes means in said body guiding said firing pin along a path that includes a first position in which said sealing portion is wholly outside said cylindrical bore portion to permit free communication between said reaction chamber and said breech bore, and a second position in which said sealing portion of the firing pin is in engagement with said cylindrical bore portion so that rapid movement of the firing pin from said first position to said second position will trap a volume of fluid in said breech bore and compress it sufficiently to ensure firing of such mixture in said breech bore.

United States Patent [19]

Singelmann et al.

[11] **4,099,445**

[45] **Jul. 11, 1978**

[54] **PRESSURE DIFFERENTIAL PISTON-COMBUSTION CHAMBER SYSTEM**

[75] Inventors: **Dietrich Singelmann**, Ottobrunn; **Heinrich Strobl**, Munich; **German Munding**, Bad Friedrichshall, all of Germany

[73] Assignee: **Messerschmitt-Bolkow-Blohm GmbH**, Munich, Germany

[21] Appl. No.: **862,637**

[22] Filed: **Sep. 22, 1969**

[30] **Foreign Application Priority Data**

Aug. 21, 1968 [DE] Fed. Rep. of Germany 1728077

[51] **Int. Cl.²** **F41F 1/04**

[52] **U.S. Cl.** **89/7; 89/8**

[58] **Field of Search** 60/26.1; 89/1, 7, 8

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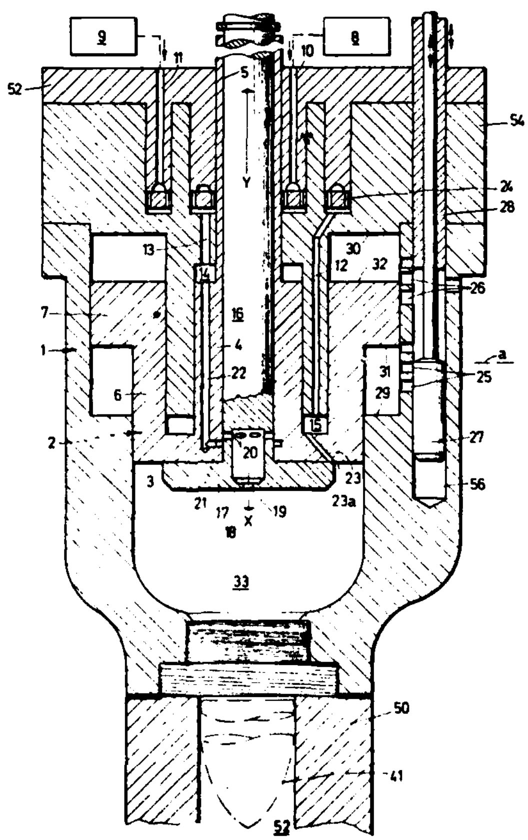
Primary Examiner—David H. Brown

Attorney, Agent, or Firm—Toren, McGeady and Stanger

[57] **ABSTRACT**

A propelling or driving force generating system for propelling a device such as projectile in a fire arm comprises a combustion chamber cylinder formed at the end of a barrel containing a bore for the passage of a projectile and in which is movable in pressure differential piston. The piston includes an annular ring portion having surfaces on respectively axially opposite ends which are exposed to pressure forces existing in intermediate chambers defined between these surfaces and end walls of the surrounding cylinder in widened annular portions of the cylinder. The cylinder and piston are provided with one or more passages for the passage of a propellant component into the combustion chamber. The various propellant components which are preferably of a nature such that they will react hypergolically, are connected through valve means in these passages and by a central plunger element of said valve means into the combustion chamber. Reaction of the components generates combustion gases in the combustion chamber to force the piston backwardly in a working stroke and to produce a force for expelling the projectile through the bore at the opposite end of the combustion chamber. The construction is characterized by an arrangement which provides an additional moving force on the piston in order to aid its working stroke movement at the initial stage of such movement.

10 Claims, 3 Drawing Figures



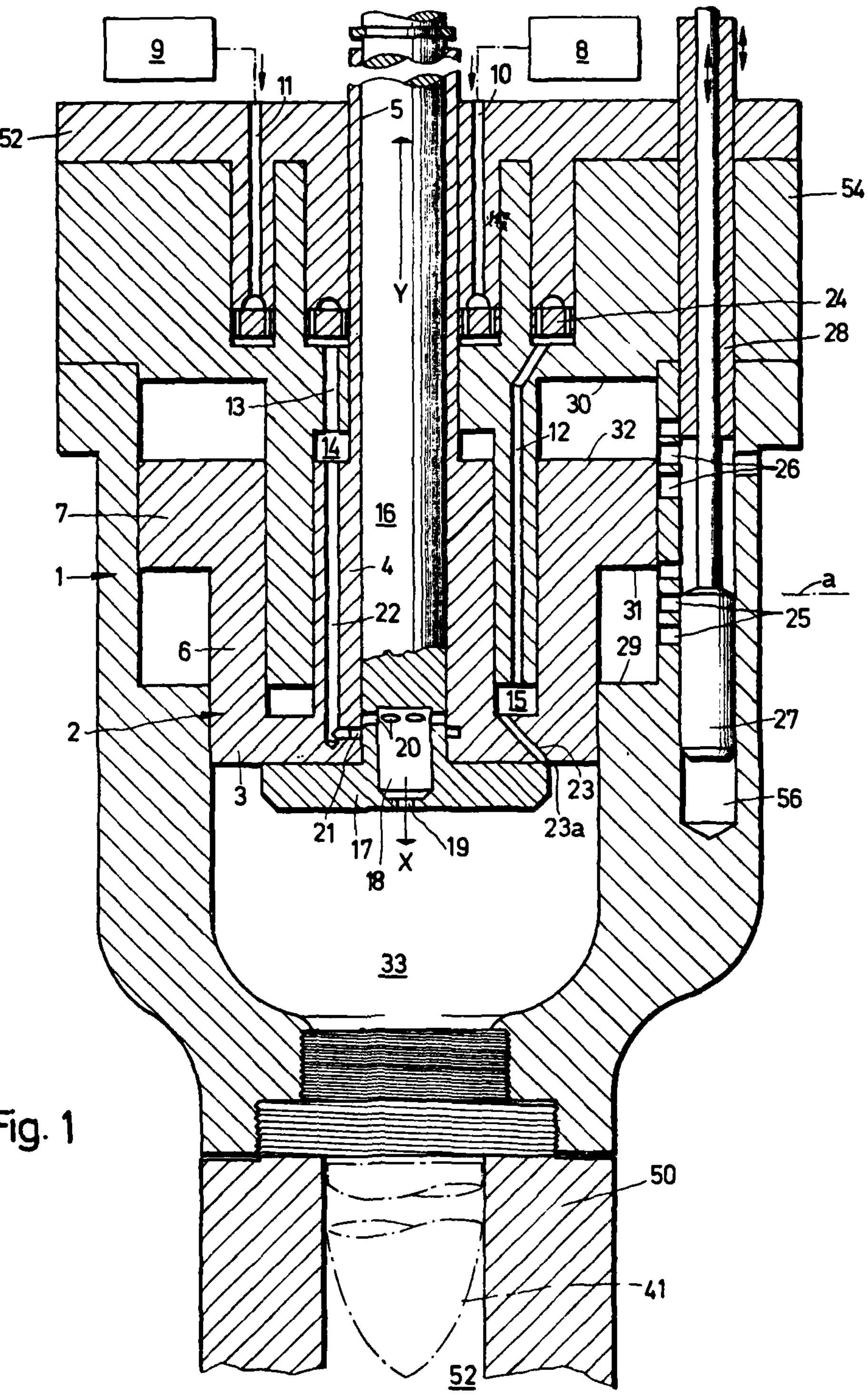

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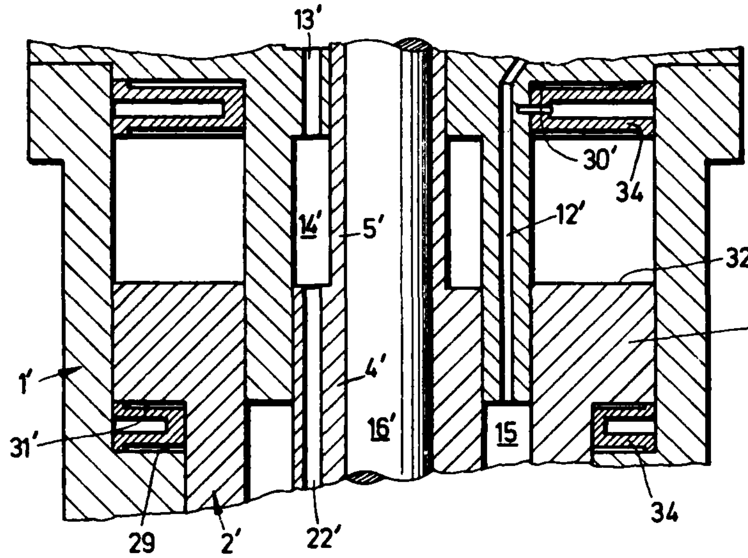
Fig. 1

Fig. 2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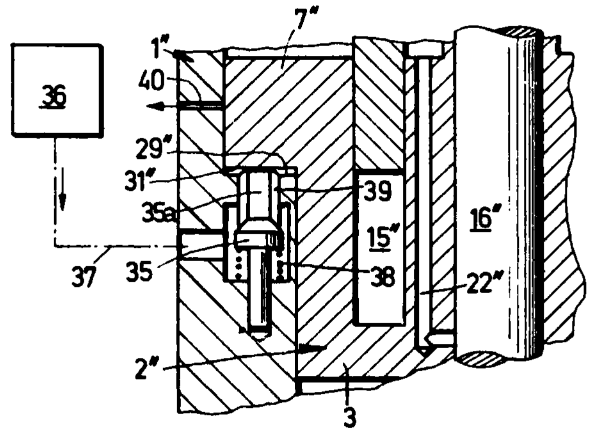
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Fig. 3

PRESSURE DIFFERENTIAL PISTON-COMBUSTION CHAMBER SYSTEM

SUMMARY OF THE INVENTION

This invention relates in general to the construction of a driving force generating system and in particular to a new and useful device for producing a driving force for propelling projectiles, such as in a fire arms, and which includes a moving pressure differential piston which is moved by the force of gases generated in a combustion chamber and which is also aided in its movement by an additional force.

The present invention is particularly concerned with the production of a pressure differential piston combustion-chamber system for the production of propelling gases from liquid propellant components, particularly hypergolically reactive components, and particularly for use in propelling a projectile from a fire arm. The system of the invention has a guide cylinder for the pressure differential piston which forms a combustion chamber casing. The front end face of the piston closes an inner space of the combustion chamber and the opposite end forms together with parts, which are stationary or fast on the casing, distribution chambers for the propellant components. A projecting annular ring portion of the piston moves in an annular widened passage of the cylinder and the forward and return movement of the piston are aided by the pressure forces acting on each end of the piston ring portion. The pistion is urged backwardly during the combustion in the combustion chamber by the combustion chamber gas pressures and while so doing it creates an injection pressure for feeding the fuel components into the combustion chamber.

U.S. Pat. No. 3,138,990, discloses a rapid fire weapon which is actuated by a pressure differential piston-combustion chamber system. In this weapon the pressure gases which propel the projectile out of the barrel are produced in the combustion chamber by means of two liquid fuel components which react hypergolically with each other. In such a construction the injection of the fuel is initiated at the front reversing point of the pressure differential piston and a partial amount of the two fuel components is first conveyed or injected into the front region of the combustion chamber by means of the fuel container pressures. Due to the reaction of the propellant components a combustion pressure builds up at this location and acts against the front of the piston and annular end sides of the pressure differential piston and moves the piston back after having overcome an initial counterforce which is caused by a pressure medium. In so doing the previously injection quantities of propellant components are put under pressure by ring members of the pressure differential piston in annular spaces or distribution chambers and they are injected into the combustion chamber. At the same time, check valves or non-return valves automatically close in a direction toward the fuel containers or supply tanks. Since the front annular end face which faces the inner space of the combustion chamber is larger than the end face of the two ring members which press on the quantities of propellant components, a differential action sets in whereby the injection pressure at any given moment is larger than the respective inner pressure of the combustion chamber.

In order to obtain a favorable inner ballistic condition it is, according to a theory of shooting, necessary that pressure gases which are produced by combustion of an amount of gun powder which is weighed into cartridges used in a conventional fire arm and which pressure gases drive the projectile out of the barrel, react at a high starting pressure in order to impart the projectile with a large initial acceleration and thus a high muzzle speed. It is true that the known fire arms which operate on the pressure differential combustion chamber principle for producing high pressure gases have certain advantages such as the saving of cartridges, less weight and less sensitivity of the used propellants. However, the known fire arms which operate on this principle have a disadvantage in respect to large initial acceleration and muzzle speed. This is true because in the initial stage of the inner ballistic procedure, that is, in the front reversing position of the pressure differential piston, the injection pressure energy which is produced will be merely that of the relatively low fuel supply container pressure. This causes a relatively flat rise of the pressure as indicated in the pressure-path diagram or in the inner ballistic work diagram. The pressure peak which is determinitive for a large initial acceleration of the projectile is obtained too late and with a loss of time in the form of an undesired staying period and only after the combustion chamber pressure starts operating and the increase of the injected propellants take place as a result thereof.

The present invention overcomes the disadvantages of the prior art by providing a driving force generating system in which the propelling gases have a steep pressure increase in respect to their pressure path diagrams so that they are made suitable for fields of utilization which require such steep pressure increase particularly for fire arms. With the invention the pressure differential piston is driven at the beginning of its working stroke during the initial phase of its movement by means of a special additional moving force. This additional moving force is active when the combustion chamber pressure has not achieved a sufficiently high driving force value and when a very large amount of propellant is injected into the combustion chamber. This produces an extremely large build-up of the combustion chamber pressure to initiate the backward movement of the pressure differential piston.

In accordance with one feature of the invention the additional driving force is provided by utilizing the kinetic energy of the forward moving pressure differential piston. This is effected by providing a gas spring or mechanical spring action on the piston so that for example the spring, or its force, is increased or tensioned by the retreating movement of the piston and will react on the piston to create an initial driving force in a working direction.

In a further embodiment of the invention, the additional driving force is obtained by the use of an extraneous pressure source which is obtained, for example, by connecting the cylinder to a storage tank of a gas such as air which is maintained under pressure. One or more pressure supply valves may be built into the combustion chamber casing in the region adjacent the annular ring portion of the pressure differential piston. Such valves are provided with sensing means which project into the path of the piston and are contacted during the return movement of the piston to supply the gas under pressure against a face of the piston to move it in an opposite direction in a working stroke. A similar arrangement may be employed at each end of the piston stroke in order to facilitate both the working stroke and the return stroke.

Accordingly, it is an object of the invention to provide improved driving force generating system for propelling a device such as a projectile which includes a differential pressure piston which is movable in the cylinder formed at the end of a barrel having a bore for the movement of a projectile therethrough, for example, and wherein the piston is moved backwardly in a working stroke by the forces of gases generated within the combustion chamber and fed into the chamber by the movement of the piston, and wherein an additional force acts on the piston during the initial portion of its working stroke in order to move it more rapidly during this portion.

A further object of the invention is to provide a fire arm device which includes a combustion chamber for the end of the barrel having a bore for the passage of a projectile therethrough, and which includes a pressure differential piston which is slidable in the combustion chamber, the combustion chamber having means for injecting propellant components therein preferably components which react hypergolically, and wherein the piston includes a widened ring portion having respectively opposite directed axially spaced end faces which are acted upon by additional force means such as a spring or a gas under pressure to move it during an initial period in each direction of movement and particularly for effecting a steep pressure increase in the combustion chamber in order to make the propellant producible therein suitable for use in driving a projectile.

A further object of the invention is to provide a driving force generating system which is simple in design, rugged in construction and economical to manufacture.

The various features of novelty which characterize the invention are pointed out with particularity in the claims annexed to and forming a part of this specification. For a better understanding of the invention, its operating advantages and specific objects attained by its use, reference should be had to the accompanying drawings and descriptive matter in which there are illustrated and described preferred embodiments of the invention.

BRIEF DESCRIPTION OF THE DRAWINGS

In the drawings:

FIG. 1 is a longitudinal sectional view of a driving force generating system constructed in accordance with the invention;

FIG. 2 is a partial sectional view similar to that indicated in FIG. 1 of another embodiment of the invention; and

FIG. 3 is a partial sectional view similar to FIG. 1 of still another embodiment of the invention.

GENERAL DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring to the drawings in particular the invention embodied therein as indicated in FIG. 1, comprises a pressure differential piston generally designated 2 which slides in a cylinder or combustion chamber casing generally designated 1. The piston 2 includes a central piston portion having a front face 3 which extends into a combustion chamber 33 which, in the embodiment illustrated, is formed at the end of a projectile barrel 50 having a passage 52 therethrough for the passage of a projectile 41.

The piston 2 includes an elongated inner piston part 4 having a bore defining a guide for valve means which includes a plunger 16 and plate valves 24. The piston 2 also includes a central cylindrical piston portion 6 which slides in the combustion chamber 33 and which has at its trailing or rear end a widened annular portion or ring 7.

Two propellant components such as an oxygen and a liquid fuel are stored in supply containers or tanks 8 and 9, respectively and they are connected through axially elongated passages 10 and 11 defined in an end plate 52 which is secured over an end cylinder wall 54. The inner or lower end of the passages 10 and 11 communicate to annular spaces having valve means in the form of individual plate valves 24. The inner annular passage which communicates with the elongated passage 10 for the oxygen communicates through the valve means to an axially elongated passage 13 terminating in an annular distribution chamber or pump chamber 14 defined between the cylinder end wall 54 and the piston interior portion 4. The outer annular passage which communicates with the liquid fuel being delivered through the passage 11 from the supply tank 9 communicates with an elongated passage 12 which terminates in the annular distribution passage or pump chamber 15 defined between the piston portion 4 and the cylinder end wall 54. The distribution passage 14 for the oxygen communicates with the elongated passage 22 which leads through a tangential passage 21 into tangential passages 20 defined around the interior of a swirl chamber 18 defined at the head portion of the plunger 16. The oxygen which is introduced into the swirl chamber 18 will be directed downwardly through a discharge nozzle 19. The liquid fuel on the other hand will move through the passage 12 and the distribution passage 15 and an inclined passage 33 through a discharge nozzle 23*a* which is normally covered by the head portion 17 of the plunger 16 but which is uncovered by the head portion when the piston begins movement in its working stroke by the forces of inertia which act. In a similar manner the passages 20 communicate with the annular supply duct 21 when the plunger 16 is moved because of inertia away from the associated piston 2. The plunger 16 is under the action of a return spring (not shown) which urges it in a direction of the arrow Y against the face 3 of the piston 2. In the position indicated in FIG. 1 the tangential bores 20 are out of alignment with the annular passage 21 so that the supply of the propellant component is blocked. Instead of the plate valves 24, check valves or non-return valves may be employed.

In accordance with the embodiment of the invention indicated in FIG. 1, means are provided to generate a moving force which acts on the piston 2 to drive the piston during an initial phase of its workings stroke and also preferably during an initial phase of its return stroke. In this embodiment, a control mechanism for acting on the respective surfaces 31 and 32 of the ring portion 7 of the piston 2 during the respective initial portions of the driving and return strokes is actuated to provide a fluid pressure driving force on these surfaces at selected stages of the movement of the piston. For this purpose control bores 25, 25 and 26,26 are in communication with a free air space and either partially cleared or blocked by means of a control piston 27 which moves in an axially defined chamber 56 of the cylinder wall 1. The additional pressure is applied in the space between the surface 31 and the boundary surface 29 to move the piston 1 in the working direction and between the surface 30 and the surface 32 to move the piston in a return direction. This additional pressure force is provided at the reversing points of the forward

and rearward movement of the piston **2** and is effected under the control of the control piston **27**.

The operation of the device indicated in FIG. **1** is a follows:

In FIG. **1**, it is assumed that the pressure differential piston **2** which is located in about its central position has started to move forward in the return movement in the direction of the arrow X. Because of the position of the control piston **27**, the two front control bores **25** are covered and thus the forwardly moving differential piston **2** compresses, by the annular portion **7**, the air which is enclosed or included between the surfaces **31** and **29**. A counterforce is thus created in this manner which causes the pressure differential piston **2** to come to rest or to stand still at the bottom of its return movement. This compressed air amounts to a tensioned gas spring which releases its stored energy immediately to the pressure differential piston **2** and thus moves the piston back in the direction of the arrow Y during the initial phase of the working stroke of the piston. In so doing the inner space of the annular pump chambers **14** and **15** becomes smaller so that a partial amount of the two propellant components such as oxygen carrier and fuel is injected into the combustion chamber as the plunger **16** with its head portion **17** is moved to the opened position through its own mass inertia force brought about the rapid movement of the piston **2** in a working direction.

The partial amounts of the two propellant components which are injected into the combustion space **33** by the additional force of the gas spring react in a hypergolic manner. When the combustion process starts, the pressure of the combustion space **33** acts on the pressure differential piston **2** to cause an additional injection of the additional remaining amount of the two propellant components into the distribution chambers **14** and **15**. In order to dampen the rearward movement of the pressure differential piston **2** for the initial acceleration in a return movement a certain amount of air is compressed in the space defined between the surfaces **30** and **32** by the annular piston portion **7**. The volume of this air is determined by the respective positions of the control sleeve **28**. As a further driving force for the pressure differential piston **2**, there is the pressure which prevails in the two propellant containers **8** and **9**.

In the embodiment indicated in FIG. **2**, similar parts are similarly designated but with a prime and in respect to a pressure differential piston **2'** which is movable within the cylinder **1'**. An annular spring **34** is arranged between the front end boundary surface **29'** and the countersurface **31'** as well as between the surface **30'** and the rear surface **32'**. These annular springs **34**, **34** give off their stored energy during the reversal of the pressure differential piston **2** at the beginning of the working stroke and also at the beginning of the return stroke.

In the embodiment illustrated in FIG. **3**, similar parts are again similar designated but with the addition of two primes. In this embodiment several pressure gas supply valves **35** in the form of controlled non-return, or check valves are disposed in the cylinder wall **1"** at a location to project into the space between the surfaces **29"** and **31"**. Each valve includes a sensing pin **35a** which projects into the path of the moving piston **2"** and it is displaced by the piston to open the valve and communicate the space between the surfaces **29"** and **31"** with a source of gas under pressure through a connecting line **37** and a supply tank **36**. The pressure air extends through grooves **39** of the valves and into the space to brake the movement of the pressure differential piston **2** at the end of its return movement and to accelerate the piston at the beginning or at the initial phase of its working stroke movement. After the piston **2** moves away from the sensing valve **35**, the valve is then again closed by spring **38**. After this the piston uncovers a bore **40** which vents through the cylinder **1"** as indicated. In the meantime a sufficient combustion pressure is built up in the combustion chamber space **33** as indicated in FIG. **1** and the gases which are formed due to combustion drive the projectile **41** through the passage **52**. The driving of the projectile is in an outward direction in accordance with the laws of inner ballistics. The piston **2** is moved into a starting position under the urging of a spring (not shown) which acts on the plunger **16** in the direction of the arrow Y.

What is claimed is:

1. A driving force generating system for propelling a device such as a projectile particularly in a fire arm, comprising wall means defining a combustion chamber, a piston movable in said combustion chamber, propellant component passage means defined in said wall means for delivering propellant components into said combustion chamber, valve means associated with said passage means permitting flow of said propellant components through said passage means into said combustion chamber, said propellant components being reactable in said combustion chamber to move said piston in a working stroke, a force accumulator connected to said piston and being responsive to movement of said piston to accumulate a drive force, and control means for causing said drive force to act on said piston at the beginning of its movement in its working stroke to aid in such movement.

2. A driving force generating system, according to claim **1**, wherein said force accumulator includes a spring means acting on said piston.

3. A driving force generating system, according to claim **1**, wherein said force accumulator comprises a chamber connected to said combustion chamber and being pressurized by the kinetic energy of the movement of said piston, said control means comprising a passage for connecting said chamber to communicate the stored pressure to said piston to aid it in its movement at the beginning of its working stroke.

4. A driving force generating system for propelling a device such as a projectile particularly in a fire arm, comprising wall means defining a combustion chamber, a piston movable in said combustion chamber, propellant component passage means defined in said wall means for delivering propellant components into said combustion chamber, valve means associated with said passage means permitting flow of said propellant components through said passage means into said combustion chamber, said propellant components being reactable in said combustion chamber to move said piston in a working stroke, and additional force means acting on said piston at the beginning of its movement in its working stroke to aid in such movement, wherein said piston has a central piston portion slidable in said combustion chamber and an annular ring portion of increased dimension, said combustion chamber having an increased dimension portion in which said ring portion is movable, the space in said combustion chamber of increased dimension defining a fluid pressure storage chamber acting on each end of the ring portions of said piston and providing means for breaking the movement of said

piston in a working direction and in a return direction and for providing a moving force for said piston in the initial stages of movement in its working direction and in the initial stages of movement in a return direction.

5. A driving force generating system. according to claim 4, including spring means disposed in the path of movement of said ring portion of said piston and acting on said ring portion to aid in its movement during initial portion of movement of its working stroke.

6. A driving force generating system, according to claim 4, including a control chamber connected to said cylinder and respective opposite sides of said ring portion of said piston, and a control piston slidable in said control chamber, said control chamber having openings at spaced locations which are covered and uncovered by movement of said piston for regulating the movement of the air by movement of said ring portion of said piston for aiding the movement of said piston in its initial portion of movement in its working stroke direction.

7. A driving force generating system for propelling a device such as a projectile particularly in a fire arm, comprising wall means defining a combustion chamber, a piston movable in said combustion chamber, propellant component passage means defined in said wall means for delivering propellant components into said combustion chamber, valve means associated with said passage means permitting flow of said propellant components through said passage means into said combustion chamber, said propellant components being reactable in said combustion chamber to move said piston in a working stroke, and additional force means acting on said piston at the beginning of its movement in its working stroke to aid in such movement, said additional force means comprising an annular spring surrounding said piston, said piston having an annular portion projecting outwardly from the sides thereof and engageable with said spring at the end of the path of movement thereof in a return direction.

8. A driving force generating system for propelling a device such as a projectile particularly in a fire arm, comprising wall means defining a combustion chamber, a piston movable in said combustion chamber, propellant component passage means defined in said wall means for delivering propellant components into said combustion chamber, valve means associated with said passage means permitting flow of propellant components through said passage means into said combustion chamber, said propellant components being reactable in said combustion chamber to move said piston in a working stroke, additional force means acting on said piston at the beginning of its movement in its working stroke to aid in such movement, said additional force means comprising a valve projecting into said wall means, said wall means including a widened wall portion, said piston having an annular ring portion of increased dimension slidable in said widened wall portion of said wall means, said valve being oriented to project into the path of movement of said ring portion of said piston and being located to open just prior to the end of the return movement of said ring portion of said piston, and means connected to said valve for supplying compressed gas through said valve when opened by said piston and into said combustion chamber to act on said ring portion to move said ring portion with said piston in a working direction.

9. A driving force generating system for propelling a projectile in a fire arm, comprising a tubular member defining a projectile bore passage and a widened combustion chamber at the end of said passage, a piston having a central portion slidable in said combustion chamber and having a widened ring portion, said tubular member having a widened portion permitting axial movement of the ring portion of said piston, propellant supply tank means, pump means connected between said propellant supply tank means and said combustion chamber and being movable by movement of said piston to pump propellant components to said combustion chamber for generating gaseous products of combustion therein and for effecting a working stroke of said piston in a direction away from said projectile passage, a force accumulator connected to said pistion and being responsive to movement of said piston to accumulate a drive force, and control means for causing said accumulated drive force to act on said piston during the initial stage of movement thereof in its working stroke.

10. A driving force generating system. according to claim 9, wherein said pump means includes an end plate closing said tubular member and having a plurality of passages defined therein, said passages and extending through said piston, and valve means associated with said passages including a plunger slidable in said piston and being movable away from said piston by inertia during the movement of said piston in a working stroke to open said passages.

* * * * *

United States Patent [19]

Hofmann

[11] **4,100,836**

[45] **Jul. 18, 1978**

[54] **COMBUSTION CHAMBER SYSTEM FOR THE PRODUCTION OF PROPELLING GASES**

[75] Inventor: **Heinrich Hofmann,** Gröbenzell, Germany

[73] Assignee: **Messerschmitt-Bölkow-Blohm Gesellschaft mit beschränkter Haftung,** Munich, Germany

[21] Appl. No.: **862,638**

[22] Filed: **Sep. 22, 1969**

[30] **Foreign Application Priority Data**

Aug. 21, 1968 [DE] Fed. Rep. of Germany 1728074

[51] **Int. Cl.**² **F41F 1/04**

[52] **U.S. Cl.** **89/7**; 89/8

[58] **Field of Search** 89/1, 7, 8; 60/26.1

[56] **References Cited**

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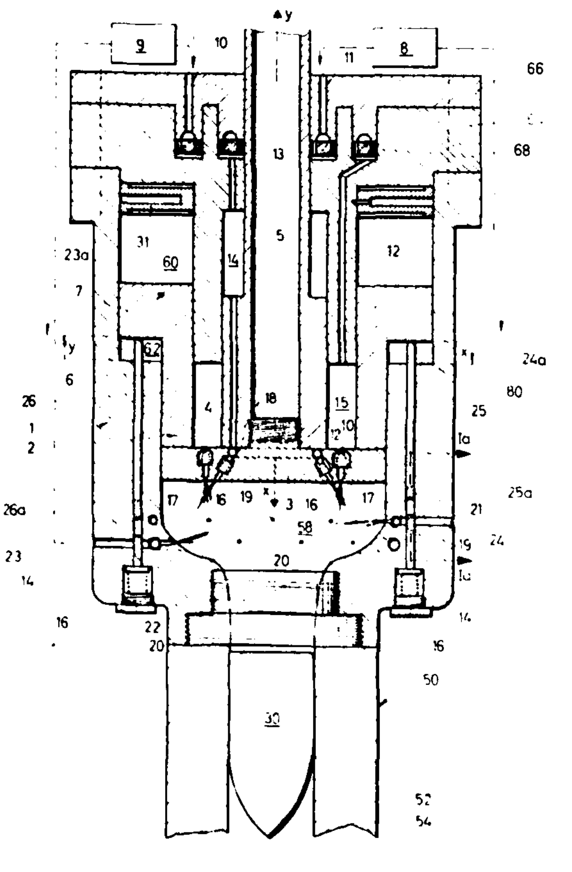
Primary Examiner—David H. Brown

Attorney, Agent, or Firm—Toren, McGeady and Stanger

[57] **ABSTRACT**

A combustion chamber system for the production of propelling gases, particularly for propelling projectiles includes a tubular member defining a combustion chamber which is adapted to be located adjacent one end of a gun barrel having a passage for a projectile. A piston is slidable in the combustion chamber toward and away from the projectile and it includes a ring portion of wider diameter which is movable in a widened portion of the tubular member defining the combustion chamber. Propellant components are introduced into the combustion chamber by the movement of the piston which is effected by the combustion of the gases within the combustion chamber. For this purpose, the combustion chamber is connected through passages defined in the piston and fixed end plates of the combustion chamber which extend to supply tanks for the various propellant components. The piston and the end plates also define distributing passages for the propellant components which are cyclicly compressed and expanded by the movement of the piston and thus produce a movement of the propellant components through nozzles defined at the end of the piston end face for injection into the combustion chamber. The apparatus includes additional means for producing pressure within the combustion chamber to cause a braking of the movement of the piston in the return direction and initiate a rapid build-up of the pressure in the combustion chamber for producing a rapid movement of the piston in a working stroke direction.

7 Claims, 4 Drawing Figures



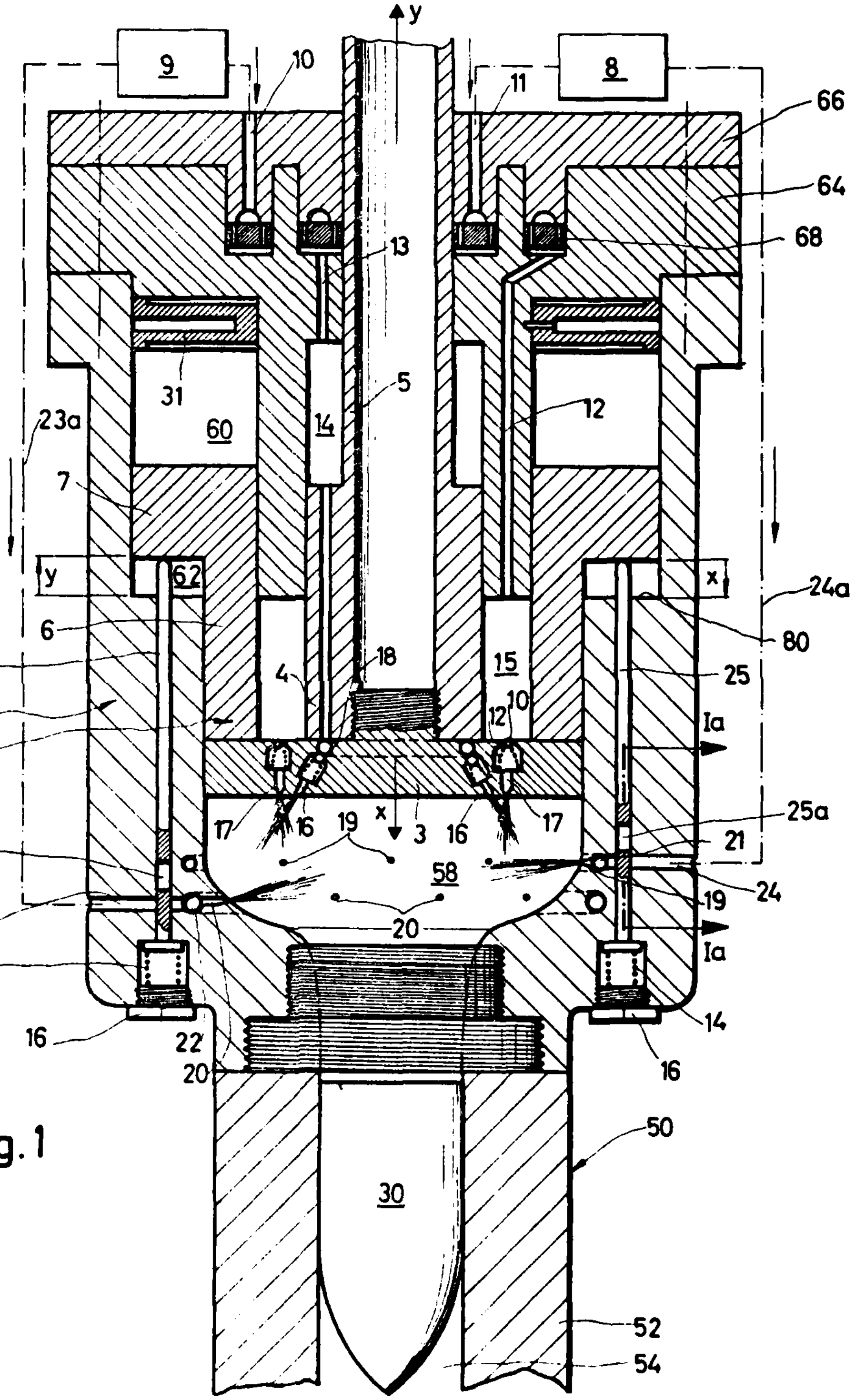


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Fig. 1

Fig. 2

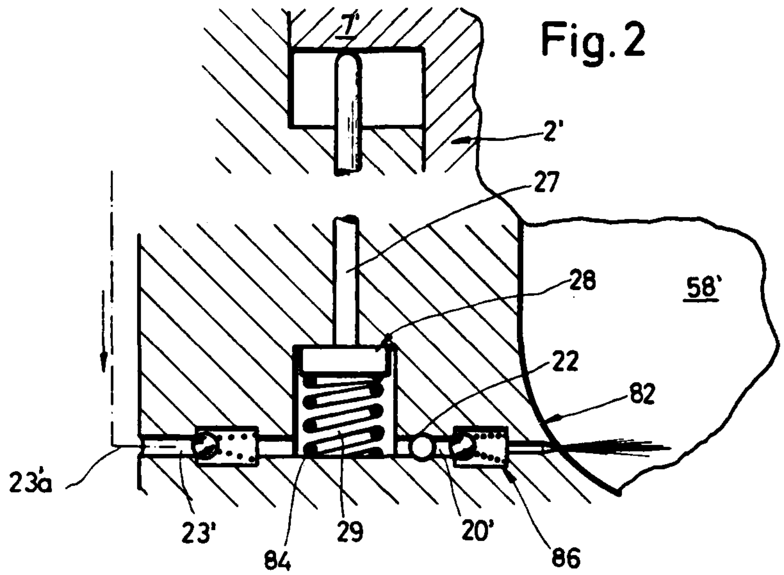


Fig. 1a

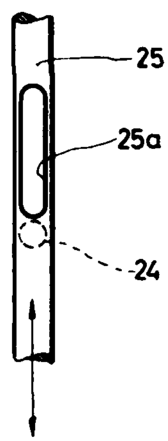
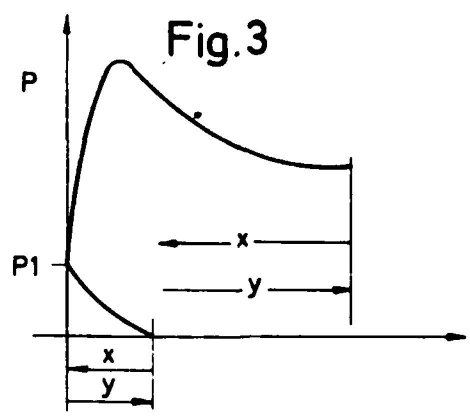


Fig. 3



COMBUSTION CHAMBER SYSTEM FOR THE PRODUCTION OF PROPELLING GASES

SUMMARY OF THE INVENTION

This invention relates in general to the construction of a propelling force producing device, and in particular, to a new and useful differential pressure piston combustion chamber system for the production of propelling gases particularly for fire arms.

The invention deals with a pressure differential piston-combustion chamber system for the production of propelling gases from liquid, particularly hypergolic propellant components, and is particularly suitable for fire arms. The system of the invention includes a guide cylinder for the pressure differential piston which also forms a combustion chamber casing and a receiving chamber for a projectile in the event that the device is to be used with fire arms. The piston closes, on its one face, the inner space of the combustion chamber, and its opposite rear face moves in a chamber defined at the opposite end of the combustion chamber, which forms a propellant distribution chamber; and thus provides means for directing the propellant components through passages into the combustion chamber.

In accordance with U.S. Pat. No. 3,138,99C, it is known to provide a rapid fire weapon which is actuated by a pressure differential piston-combustion chamber system. With such a system, the pressure gases which propell the projectile out of the barrel are produced in the combustion chamber by means of two liquid fuel components which react hypergolically with each other. In this construction, the injection of the fuel is initiated at the forward end reversing point of movement of the pressure differential piston and part of the fuel components are conveyed or injected into the combustion chamber by means of the existing pressures of the supply containers or tanks. The reaction of the fuel components produces a combustion pressure build up in the combustion chamber which acts against the front ends of an annular side ring of the piston to move the piston backwardly after it overcomes an initial counterface which is caused by a pressure medium. In so doing, the previously injected fuel components are put under pressure by associated ring members or portions of the pressure differential piston which move in an annular spaces or distribution chambers to cause the components to be directed into the combustion chamber. At the same time check valves or non-return valves are automatically closed in a direction toward the fuel containers. Since the front annular end face of the differential piston which faces to the combustion chamber is larger than the end faces of the ring portions which act on the fuel distribution chambers, a differential action sets in whereby the injection pressure at any given moment is larger than the respective inner pressure of the combustion chamber.

In order to obtain favorable inner ballistic conditions it is, in accordance with the theory of shooting, necessary that the pressure gases which are produced by combustion of the amount of gun powder which is weighed in the cartridges employed conventional fire arms, and which is employed to drive the projectile out of the barrel, must reach a high starting pressure in order to impart to the projectile and an initial acceleration which is large enough so that a high muzzle speed is attained. The known fire arm which operates on a pressure differential combustion chamber principle for

producing pressure gases have certain advantages over conventional fire arms including savings in respect to the cartridges less weight, and less sensitivity of the used propellants. However, these known fire arms which operate under this principle have a disadvantage in respect to large initial acceleration, and large muzzle speed. This is because, during the initial stage of movement of the pressure differential piston in the working stroke direction, the injection pressure energy which develops will be only that which is attained from the relatively low fuel supply container pressure. This causes a relatively flat rise of the pressure curve in the pressure-path diagram or in the inner ballistic working diagram. The pressure peak, which is determinitive of a large initial acceleration of the projectile, is thus attained too late and with a loss of time in the form of an undesired staying period which occurs after the combustion chamber pressure starts operating. Therefore, there is an increase in the quantities of the fuel components which are injected.

The present invention provides a construction in which overcomes disadvantages of the prior art and provides a propelling force having a steep pressure increase in the pressure-path diagram making the device suitable for use in a fire arm. This is solved by providing a pre-injection of a partial amount of the propellant components during the end portion of the forward movement of the pressure differential piston which occurs during its return stroke. This is done if necessary by additional injection of a further partial amount of the propellant components during the last portion of the return stroke and during an initial phase of the working stroke movement of the differential piston. By providing a pre-injection, the ignition delay time will still produce an ignition in the end phase of the forward movement of the pressure differential piston so that the ignition delay time will not constitute an unavoidable dead time or lost time. The invention provides an additional important advantage over the prior art in that as soon as the pressure differential piston has reached its front dead end position, a certain pressure will already be built up ahead of it without requiring any delay or staying time of the piston in the front dead end position. Due to this pre-pressuring of the combustion chamber, the differential piston will be pushed backwardly at high speed into the working stroke. Additional fuel is injected through the pressure differential piston into the combustion chamber. The pressure gas cushion which is produced by a pre-injection into the combustion chamber forms a spring which elastically brakes the forward return movement of the piston.

The control of the pre-injection is affected by the movement of the differential piston itself and is advantageously carried out by means of push rods having ends which project into the cylinder space and are contacted by ring portions of the piston and displaced to permit opening of the passages for the particular propellant components so that they are sprayed into the combustion chamber under the container pressure, or the push rods actuate individual injection pumps which spray this propellant components into the combustion chamber under additional pressure. The arrangement is such that there is no lost time in the operation of the differential piston and in addition a greater initial acceleration of the pressure differential piston is carried out and an increase of the shooting frequency is obtained. Due to the advantageous arrangement the constructional

length of the combustion chamber may also be shortened.

Accordingly, it is an object of the invention to provide a driving force generating system using a pressure differential piston movable in a combustion chamber by the combustion gases generated between and acting during its movement to pump propellant components into the combustion chamber and also including means for directing an additional amount of propellant components into a combustion chamber just prior to and during an initial portion of movement of the piston in a working stroke.

A further object of the invention is to provide a driving force generating device which is simple in design, rugged in construction, and economical to manufacture.

The various features of novelty which characterize the invention are pointed out with part of this specification. For a better understanding of the invention, its operating advantages and specific objects attained by its use, reference should be had to the accompanying drawings and descriptive matter in which there are illustrated and described preferred embodiments of the invention.

BRIEF DESCRIPTION OF THE DRAWINGS

In the drawings:

FIG. 1 is an axially sectional view of a fire arm constructed in accordance with the invention;

FIG. 2 is a partial axial sectional view of another embodiment of fire arms;

FIG. 1*a* is a section taken on the line 1*a*—1*a* of FIG. 1; and

FIG. 3 indicates a pressure-path diagram of the combustion chamber system.

GENERAL DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring to the drawings in particular, the invention embodied therein in FIG. 1 comprises a driving force generating system in the form of a fire arm generally designated **50** which includes a barrel portion **52** having a bore or passageway **54** for the passage of a projectile **30**. The barrel **52** is formed as an extension or as a separate piece extending outwardly from a tubular member or cylinder generally designated **1** which defines a central combustion chamber **58** and annular differential pressure chambers **60** and **62**. The end of the cylinder **1** is closed by a fuel passage plate member **64** and a fuel passage disk **66**.

In accordance with the invention, a pressure differential piston **2** is arranged to slide in the combustion chamber **58** and it includes a bottom or end face portion **3** and an annular rear portion or ring **4** which moves in the passages **60** and **62**. In addition, the pressure differential piston **2** includes an inner guide pipe portion or cylindrical portion **5** which is spaced radially inwardly from an outer skirt portion **6**.

The propellant components, for example, a liquid fuel and an oxygen or an oxygen carrier, are stored in supply containers or tanks **8** and **9**, respectively. The respective tanks **8** and **9** are connected, through axially elongated passages **11** and **10**, valve means in the form of plate valves **68**, and further passages **12** and **13**, to respective annular distribution chambers **15** and **14** which vary in size in accordance with the position of the piston **2**. The piston bottom **3** carries associated bores and nozzle means **16** and **17** for the fuel and oxygen spray deliveries into the combustion chamber **58**. The nozzle means and **16** and **17** include ball valves **70** biased to a closed position by springs **72**. The pressure force of the spring **72** is overcome during the upward movement of the piston **2** on a working stroke by the collapsing of the respective annular chambers **15** and **14**, for the fuel and oxygen respectively, caused by this upward piston movement. The nozzle means **16** are connected to the supply through an annular passage **18** which is defined in the bottom **3**. The discharge of the nozzle means **16** and **17** is oriented obliquely so that the spray streams intersect and provide mixing of the components adjacent the point of introduction to the combustion chamber **58**.

In accordance with a feature of the invention a rapid increase in the pressure within the combustion chamber **58** is obtained during the return downward movement of the piston **2** in order to provide a rapid build up for the working stroke in the upward direction. To accomplish this, means are added to the combustion chamber for effecting a rapid build up of a force in the form of a pre-injection or predetermined amount of fuel and oxygen carrier. For this purpose, the walls of the combustion chamber **58** are provided at a plurality of spaced locations around the periphery and above the bottom dead center position with injection bores **19** and **20** which extend obliquely relative to each other in order to provide a whirling impinging effect of the injected propellants. Annular passages **21** and **22** which are defined in the cylinder walls communicate with the individual injection bores **19** and **20** respectively and they are supplied from the propellant containers **8** and **9** through connecting lines **24*a***, **24** and **23*a***, **23** respectively. The passages **24** and **23** are closed by a surface of a respective push rods or central rods **25** and **26** which are slidable in axially extending passages of the cylinder **1**. The control rods **25** and **26** project into the annular space **62** and they are contacted by the ring portion **7** of the piston **2** during its downward movement and moved against the force of a spring **74**, which is retained over a nut **76** threaded into the cylinder **1**, to move the rods downwardly during this downward movement of the piston. When this downward movement occurs associated slot passages **25*a*** and **26*a*** are moved into alignment with the passages **24** and **23** respectively to open these passage to admit the associated propellant components to be sprayed into the combustion chamber **58**.

The operation of the device is as follows:

During the return movement of the differential pressure piston **2**, in a downward direction as viewed in the drawings, it reaches the point in the drawings at which is it spaced by a distance X from a ledge **80** of the cylinder. At this location it contacts the tops of the associated push rods **25** and **26**. The distances X (return) and Y (working stroke) may be equal or of a different amount depending upon the of combustion characteristics which are to be obtained. Upon further downward movement of the piston **2** from the position indicated in FIG. **1** the push rods **25** and **26** are moved downwardly so that the supply bores **25** and **23** are opened for the discharge of the associated propellant components into the combustion **58**. By such an introduction of the propellant components the pressure will rise in the combustion chamber during the end phase of movement of the piston **2** and its return stroke, so that as the piston approaches a reversing position at the bottom dead center, a certain pressure $p1$ is exerted on the pressure differential piston **2** which imparts to the piston an immediate starting acceleration for its working stroke. At the same time, the fuel injection from the nozzles **16** and **17** be-

comes greater. During the initial upward movement in the working stroke, comparable to the phase distance Y, an additional amount of propellant is injected from the preinjection bores **19** and **20** because the control slots **25***a* and **26***a* will still be partially aligned with the passages **24** and **23** respectively. Thus the inertia pressure is still further increased. After the end of the return movement and during the beginning of the upward movement in the phase Y of the working stroke the pre-injection and the additional injection will be interrupted by the complete return of the push rods **25** and **26**. In the further course of the working stroke the additional propellant which is injected by the nozzle means **16** and **1 7** will also be discontinued.

In the embodiment indicated in FIG. **2**, similar parts are similarly designated for a driving force generating system generally designated **82**. In this arrangement, the differential pressure piston **2'** actuates, with an annular piston portion **7'**, drive pushers **27** of one or more injection pumps generally designated **28**. The pumps **28** include a spring **84** which urges a pusher **27** upwardly and it includes a pumping space **29** which communicates with suction passages **23'** and **23***a'* and discharge passages **20'** which are connected with combustion chamber discharge nozzle means **86**.

In each embodiment the pressure gases which are formed due to the combustion within the combustion chamber **58** or **58'** drive a projectile **30** which has been inserted by means of suitable loading devices (not shown) into the barrel **52**. The projectile **30** is moved out of high muzzle velocity according to the laws of inner ballistic.

As a starting position or rest position, there is provided a reversing point of the pressure differential piston **2** into which the piston is brought in each case by means of a spring (not shown) which acts in the direction of the arrow Y. A ring spring **31** forms a rear abutment for a pressure differential piston **2** for reversing the piston from the upward working stroke to the downward return stroke. The forward working stroke movement of the pressure differential piston **2** is also aided by the pressure of the tanks **8** and **9**.

What is claimed is:

1. A driving force generating system, particularly for propelling a device such as a projectile in a fire arm, comprising wall means defining a combustion chamber, a piston movable in said combustion chamber, propellant component supply tank means, pump means connected between said supply tank means and said combustion chamber and being operable by movement of said piston in a working stroke to deliver propellant components into said combustion chamber, additional propellant supply means connected between said propellant supply tank means and said combustion chamber, nozzle means associated with said supply means for discharging the propellant into said combustion chamber, a control member disposed in the path of said piston, a spring biasing said control member in a direction to project it into the path of movement of said piston, said control member being contractable by said piston in a return movement to move it against the force of said spring to cause the discharge of propellant from said nozzle means for directing an additional amount of propellant components from said supply tank means into said combustion chamber toward the end of the return movement of said piston.

2. A driving force generating system, particularly for propelling a device such as a projectile in a fire arm, comprising wall means defining a combustion chamber, a piston movable in said combustion chamber, propellant component supply tank means, pump means connected between said supply tank means and said combustion chamber and being operable by movement of said piston in a working stroke to deliver propellant components into said combustion chamber, additional propellant supply means connected between said propellant supply tank means and said combustion chamber, nozzle means associated with said supply means for discharging the propellant into said combustion chamber, a control member disposed in the path of said piston, a spring biasing said control member in a direction to project it into the path of movement of said piston, said control member being contractable by said piston in a return movement to move it against the force of said spring to cause the discharge of propellant from said nozzle means for directing an additional amount of propellant components from said supply tank means into said combustion chamber toward the end of the return movement of said piston, including propellant component passage means defined in said piston and said walls means for delivering propellant components through said piston into said combustion chamber, said piston and said wall means defining a pumping chamber therebetween connected to said component supply tank means and providing a pumping action in respect to said chamber by movement of said piston during a working stroke and comprising said pump means.

3. A driving force generating system, for propelling a device such as a projectile comprising a tubular member defining a central combustion chamber which is adapted to be connected at one end to a fire arm barrel, a piston slidable in said combustion chamber, end plate means closing said tubular member and defining at the rear of said piston a plurality of pumping chambers which collapse upon movement of said piston in one direction and enlarge upon movement of said piston in said opposite direction, means for supplying individual propellant components to respective ones of said chambers, passage means connecting said chambers to said combustion chamber for injecting said propellant components into said combustion chambers during the movement of said piston in which the pumping chambers are collapsed, a plurality of control members of a number corresponding to the number of propellant components disposed in a path of movement of said piston and engageable by said piston during the return stroke thereof, and additional propellant component injection means for each of said propellant components connected to said control members and being actuable by movement of said control members by the return movement of said piston to provide an additional injection of propellant components into said combustion chamber.

4. A driving force generating system, according to claim **3**, wherein said control members comprise elongated rods having a passage slot defined therethrough, said injection means including a conduit connected between a propellant storage tank and said combustion chamber, said control rod blocking said conduit but having a slot therein which may be aligned therewith when moved by said piston to provide passage of the propellant component through said conduit and into said combustion chamber.

5. A driving force generating syste, according to claim **3**, including a gun barrel connected to said combustion chamber at the end opposite to said piston and

adapted to contain projectile which is driven by the generation of combustion gases in said combustion chamber, and a return spring carried at the opposite end of said cylinder from said gun barrel and engageable with said piston to urge said piston in a return movement direction.

6. A driving force generating system, according to claim 3, wherein said additional propellant component injection means comprises a propellant component pump, a drive plunger member for said pump having a portion exposed in the path of movement of said piston and being movable by said piston to pump a propellant component into said combustion chamber.

7. A driving force generating system, according to claim 6, including valve means connected to said pump for facilitating inlet to said pump and discharge from said pump.

* * * * *

UNASSIGNED PATENTS

Patent Number: 2,965,000
Author: L. A. Skinner
Title: Liquid Propellant, Regenerative Feed and Recoilless Gun
Date: December 20, 1960

Patent Number: 3,673,917
Author: Herman A. Myers, Lake Lynn, PA
Title: Liquid Fuel Operated Automatic Weapons
Date: July 4, 1972

Patent Number: 4,062,266
Author: Lester C. Elmore, Portola Valley, CA; Thomas M. Broxholm, Palo Alto, CA
Title: Liquid Propellant Modular Gun Incorporating Dual Cam Operation and Internal Water Cooling
Date: December 13, 1977

Dec. 20, 1960 L. A. SKINNER 2,965,000
LIQUID PROPELLANT, REGENERATIVE FEED AND RECOILLESS GUN
Filed Nov. 7, 1951 2 Sheets-Sheet 1

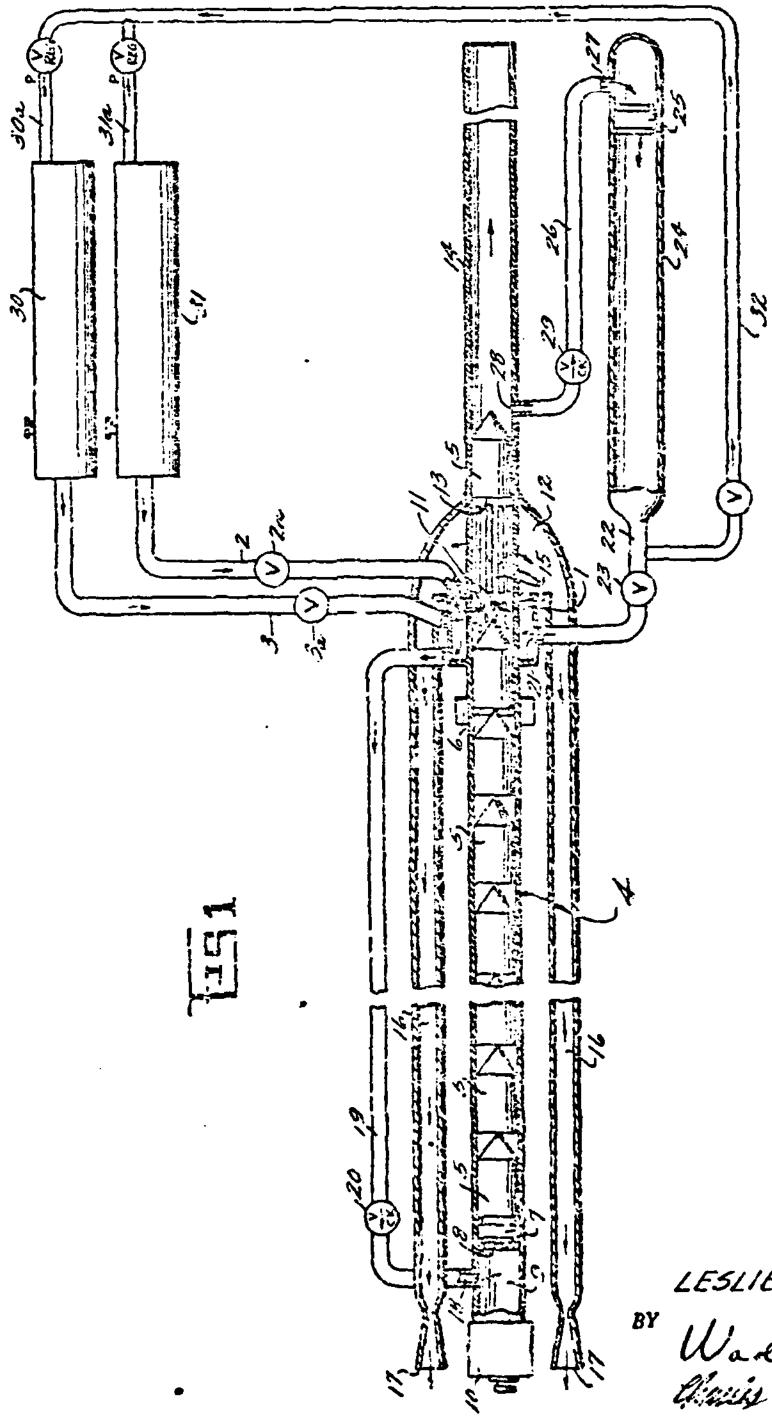


FIG. 1

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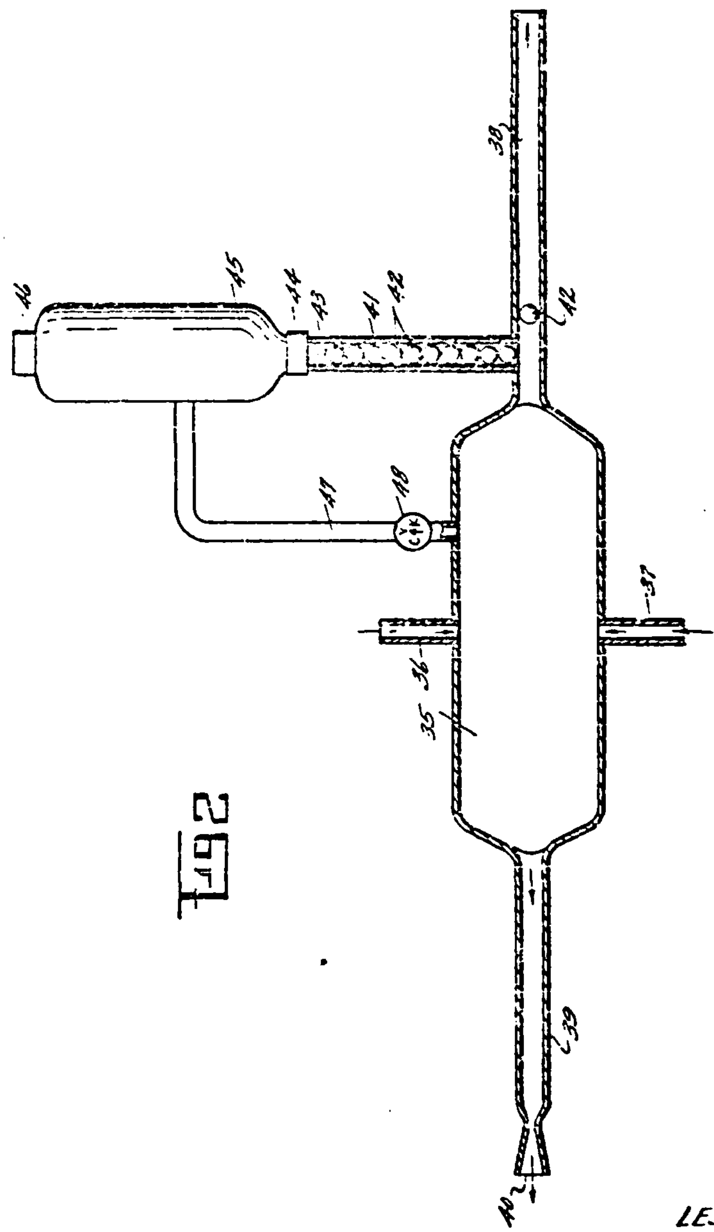

FIG. 2

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United States Patent Office 2,965,000 Patented Dec. 20, 1960

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2,965,000

LIQUID PROPELLANT, REGENERATIVE FEED AND RECOILLESS GUN

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Filed Nov. 7, 1951, Ser. No. 255,294

8 Claims. (Cl. 89—1.7)

(Granted under Title 35, U.S. Code (1952), sec. 266)

The invention herein described may be manufactured and used by or for the Government for governmental purposes without payment to me of any royalty thereon.

This invention relates to recoilless guns, intended primarily for use in military aircraft, employing liquid propellants and has for an object the provision of a gun having simplicity of design, light-weight, high cyclic rate of fire, employing large caliber shells and having a form suited especially to fixed mounting in aircraft, having conventional gun accuracy of fire with very low or complete lack of recoil.

The invention utilizes a thin walled gun tube or barrel and employs liquid propellants of the hypergolic types for creating the operating pressures for discharging the projectiles from the gun barrel or tube and actuating the repeated firing or automatic operational cycles of the gun. The gun includes enlarged gas or combustion and pressure chambers at the inner end of the gun tube with gas exhaust conduits or tubes extending rearwardly from the pressure chamber having restricted gas discharge nozzles at their rear ends for counteracting recoil.

A projectile feeding magazine is connected at its rear end to the combustion chamber by a pressure supply conduit for introducing pressure chamber pressure into the projectile feeding tube behind the projectiles so as to feed them into the gun tube one at a time, a check valve being interposed in the connection, a pressure regulator being provided to control the maximum projectile feeding pressure. Holding means is provided in the feeding tube for retaining the projectiles in the feeding tube against rearward movement while projectiles are being discharged from the gun barrel or tube, also while pressure is built up in the gun tube for subsequent discharge of a projectile therefrom.

The maximum regulated pressure in the rear end of the projectile or shell feeding magazine tube is employed, following a discharge of a projectile or shell from the gun tube, so that when a reduction of the pressure in the combustion chamber below the pressure in the tube occurs the differential pressure projects a fresh shell from the feeding tube into the gun tube.

Means are provided for introducing hypergolic liquid propellants, such as aniline and an oxidizer such as nitric acid, or H_2O_2 and alcohol and water, or NO_2 plus alcohol or NO_2, or Hydrazine (N_2H_4), or H_2O and NH_3, or many others of adequate energy and logistic properties, into the combustion chamber to build up and maintain the projectile discharging pressure within the gun tube and pressure chamber and to maintain a predetermined pressure differential between the combustion chamber and the shell feeding magazine for feeding a projectile from the magazine tube into the gun tube each time a projectile is discharged from the gun tube or barrel, means being also provided for storing up an initial gas pressure for initiating the firing cycle of the gun.

The principle of operation of my automatic gun device is to maintain a predetermined minimum working pressure in the combustion and pressure chambers at all times during the operation of the gun by feeding hypergolic liquid propellants into the combustion chamber at predetermined rates to produce this pressure and conveying this pressure into a pressure chamber at the rear end of the shell feeding magazine tube behind a piston therein for feeding or advancing the projectiles forwardly toward the gun barrel or tube, a pressure regulator being provided in the magazine tube for maintaining the projectile feeding tube pressure at a predetermined value which is slightly higher than the minimum combustion chamber pressure, whereby when a projectile is fed forwardly by the above differential minimum pressures into the gun tube the projectile will temporarily block the gun barrel to permit the combustion chamber pressure to build up to a predetermined maximum working pressure for driving the projectile through the gun barrel. The exhaust nozzles at the rear ends of the rearwardly extending exhaust tubes from the combustion chamber are so proportioned relative to the area of the gun barrel to minimize the recoil caused by gases being discharged forwardly through the gun barrel following each discharge of a projectile or shell.

Other objects and advantages of the invention will become apparent from the following description taken in connection with the accompanying drawings in which like reference characters refer to like parts in the several figures.

Drawings

Figure 1 is a somewhat schematic longitudinal sectional view through an improved gun construction incorporating my invention.

Figure 2 is a schematic longitudinal sectional view through a slightly modified form of liquid hypergolic propellant actuated gun, incorporating my invention.

Referring to Figure 1, the reference number 1 denotes a combustion or fuel mixing and burning chamber having liquid propellant supply conduits 2 and 3 connected thereto for supplying hypergolic propellants into the combustion chamber 1 in desired quantities or at desired rates. Suitable control valves 2^a and 3^a may be provided for controlling the rates of delivery of the propellants into the combustion chamber 1. These valves may be of the conventional pressure controlled or regulated types.

The combustion chamber 1 surrounds the forward end of a projectile or shell feeding tube or magazine 4 which is adapted to receive a plurality of projectiles or explosive shells 5, the length of the tube 4 being determined by the number of projectiles to be handled therein. Latch or holding means 6 is provided for engagement with the first of the shells 5 in the magazine tube 4, preferably at its rear end, to prevent rearward movement of that shell once it has been advanced into the forward end of the magazine tube 4. A piston or follower member 7 is disposed in the rear end of the magazine tube 4, stop means 8 being disposed in the magazine in the rear of the piston 7 to prevent rearward travel of the piston beyond the position shown in Figure 1 leaving a gas pressure chamber 9 between the piston 7 and the rear end of the magazine tube 4. A maximum pressure regulating valve 10 is disposed in the closure for the rear end of the tube 4, this valve is adjusted to limit the maximum pressure in the chamber 9 operable against the piston follower 7.

Ports or apertures 11 are formed in the front end of the magazine tube 4 and lead from the combustion chamber 1 through the front end of the magazine tube 4 into the gun pressure chamber 12, the front end of the pressure chamber 12 having an opening 13 in communication with a gun tube or barrel 14 disposed in axial

alignment with the magazine tube 4 with its rear end spaced from the forward end of the magazine tube 4. Projectile or shell guide bars 15 may be provided to bridge the gap between the adjacent spaced ends of the magazine feeding and gun tubes 4 and 14 for guiding the shells into the breech end of the gun barrel.

Extending rearwardly at opposite sides of the magazine tube 4, from the gun pressure chamber 12, is a pair of recoil absorbing exhaust tubes 16, each tube having a restricted discharge nozzle 17 facing rearwardly. The exhaust tubes 16 function to reduce the recoil by opposing the recoil thrust pressure of the gases from the combustion and pressure chambers 1 and 12 leaving the gun tube 14, the nozzles 17 constituting jet means facing rearwards for producing forward thrust on the gun unit as a whole in proportion to the pressure within the gun pressure chamber 12.

The magazine or shell feeding tube 4 has a gas inlet port 18 located adjacent the rear end thereof between the piston member 7 and the pressure regulating valve 10. A gas supply or pressure conduit 19 is connected to this gas inlet port 18 at one end and at its other end to the combustion chamber 1 and contains a check valve 20 opening toward the magazine tube, permitting gas and pressure to pass from the combustion chamber 1 through the conduit 19 into the magazine tube 4 behind the follower piston member 7 but preventing leakage of gas or pressure in the opposite direction through the port 18. The combustion chamber 1 also has a gas or pressure discharge port 21 in communication with a gas delivery conduit 22 having a control valve 23 therein, the conduit 22 being connected to an enlarged pressure storage chamber 24 disposed in parallel relation at one side of the gun barrel 14. The pressure storage chamber 24 comprises a cylinder having a piston member 25 arranged to travel therein intermediate its ends. A conduit 26 is connected at one end to a port 27 formed in the forward closed end of the storage chamber 24, the other end of this conduit 26 being connected to a port 28 in the wall of the gun barrel or shell 14, slightly forward of the position occupied by a shell or projectile when it is first introduced into the gun barrel. Check valve 29 is located in the conduit 26 to permit gas and pressure flow from the pressure chamber 12 into the pressure storage chamber 24 after the projectile or shell 5 in the gun barrel moves forwardly and uncovers the port 28. With the control valve 23 closed, each time a projectile 5 is discharged from the gun barrel 14 and the port 28 is uncovered the combustion chamber pressure becomes effective in the storage tube or chamber 24 to move the piston 25 to the left as shown in Figure 1 to increase the pressure in the pressure storage tube 24. This stored pressure in chamber 24 provides means for discharging the initial projectile or round 5 from the magazine tube 4 into the breech of the gun barrel 14, when the control valve 23 is initially opened. Pressure from the pressure storage chamber 24 can also be used to pressurize the hypergolic liquid propellant supply tanks, shown diagrammatically at 30 and 31 by connecting the tanks 30 and 31 to the storage chamber 24 by conduits 30^a and 31^a each having a control valve 30^c and 31^c therein connected to a common supply conduit 32.

In the operation of the gun shown in Figure 1 it will be assumed that the magazine barrel or tube 4 has been loaded, either through its rear end by removal of the pressured regulator device or through a loading port in its side. Opening of the valve 23 admits pressure to the combustion chamber 1. This pressure, through the conduit 19, creates pressure in the chamber 9 at the rear end of the magazine tube 4, causing the piston number 7 to advance the first projectile or shell 5 into the rear end or breach portion of the gun barrel 14. When the hypergolic liquid propellants from the tanks 30 and 31 are admitted into the combustion chamber 1 in suitably regulated ratios these burn, causing the pressure to rise quickly in the gun pressure chamber 12, for instance to perhaps 10,000 pounds per square inch. This pressure becomes effective to drive the first projectile 5 out of the gun tube at high velocity and due to the continued inflow of the propellant components this pressure remains at near that constant value throughout the passage of the shell 5 through the barrel 14. This pressure also becomes effective, due to the rearward jet discharge of the pressure through the exhaust tubes and nozzles 17, to exert forward thrust on the gun unit to reduce or eliminate the recoil thrust caused by the gases leaving the gun tube 14, the exhaust tubes 16 having substantially the same cross sectional area as that of the gun barrel 14. After the shell leaves the barrel 14 the pressure in the barrel and combustion chamber 1 drops, but the rate or quantity of propellant flow is substantially constant and is such as to still maintain a considerable pressure in the pressure chamber 12 of say about 5,000 pounds per square inch.

Gas under pressure in the meantime is being bled through the conduit 19 and check valve 20 into the gas chamber 9 and its pressure is immediately released down to the slightly above the minimum gun pressure chamber pressure, say about 5,200 pounds per square inch, thereby rebuilding the pressure chamber in 9 to its original 5200 pound value following the increase in volume of this chamber by one shell, due to the expenditure of one shell. When the first shell 5 leaves the muzzle and the gases are exhausted both fore and aft from tubes 14 and 16 the pressure in the combustion chamber 1 and in the gun pressure chamber 12 drops to the predetermined minimum say about 5000 pounds per square inch, permitting the higher regulated pressure of 5200 pounds per square inch in gas chamber 9 to force the next shell or projectile 5 forwardly into the breach of the gun barrel 14 and again close the gun tube 14, causing the pressure in chamber 12 to again increase to the maximum, or about 10,000 pounds as the second shell 5 is discharged through the tube 14.

Cylinders or tanks 30 and 31 containing the components of the propellant and pressurized and replenished as to pressure in the same manner as is the ammunition feed or magazine tube 4. As the shell 5 leaves its initial seating position in the breach of the barrel 14 the port 28 in gun tube 14 is uncovered, and the higher pressure of say 10,000 pounds becomes effective to pressurize the tanks 30 and 31 to a substantially similar amount of pressure. Fuel flow, once started is governed entirely by transient pressure ratios in the storage chamber 24 and in the gas chamber 12.

The gun tube 14 is preferably relatively long so that high velocities result from the use of low gun barrel pressures. This also permits the use of a gun tube having a relatively thin wall. Since hypergolic fuels are proposed no separate ignition system is required. The gun barrel may be rifled, also conical or cylindrical projectiles or shells may be employed.

Referring to the slightly modified form of the invention, as illustrated in Figure 2, the reference number 35 denotes a combustion or pressure chamber having hypergolic liquid repellant supply conduits 36 and 37 connected thereto, one of the conduits, for instance 36, supplying fuel into the combustion chamber under pressure from a supply tank not shown while the other conduit supplies the liquid oxidizer component into the combustion chamber under pressure from a suitable oxidizer tank (not shown). The hypergolic fuel and oxidizer liquid components are supplied at predetermined rates under the control of suitable valves and pressure regulators to maintain a predetermined minimum working pressure in the combustion, for example of 3,000 pounds per square inch.

Extending forwardly from the front end wall of the combustion chamber 35 is the gun tube or barrel 38

while a recoil absorbing exhaust tube 39, having a similar cross section to that of the barrel 38, extends from the combustion chamber in the opposite direction, a restricted exhaust nozzle being formed on the rear end of the exhaust tube 39.

Hypergolic liquid propellants are fed into the combustion chamber at predetermined uniform rates or ratios to maintain the minimum predetermined pressure in the combustion chamber of, for instance 3,000 pounds when there is no projectile or obstruction in the gun barrel 38. Under these conditions the gases from the combustion chamber discharge forwardly and at the same time rearwardly through the gun barrel and exhaust tubes respectively, the rearwardly extending exhaust tube discharge or thrust opposing the rearward thrust caused by the gas discharge forwardly through the gun barrel 38. In other words, the exhaust tube discharge eliminates or counteracts the recoil action of the gun tube discharge. Located in front of the combustion chamber 35, and extending upwardly from the gun tube, is a projectile supply and feeding tube or magazine 41. This tube 41 opens at its lower end into the upper half of the gun barrel 38 at a slight distance forwardly of the front end of the combustion or pressure chamber 35. The magazine 41 is sufficiently long to contain a desired number of projectiles or balls 42, and is preferably cylindrical to receive a piston member and gas seal 43, means also being provided in the form of a ratchet member or reverse motion check device 44 permitting movement of the piston 43 downwardly but resisting movement of the piston and gas seal or the projectiles in the opposite or upward direction. The upper portion of the magazine tube 41 is enlarged as shown in the drawings to provide an elongated pressure chamber 45 having a pressure regulator 46 in the upper end thereof for controlling the maximum pressure in the chamber 45 so as to maintain the same at a slightly greater pressure than the minimum controlled pressure in the combustion chamber 35, for instance, to maintain pressure in the chamber 45 at 3,100 pounds per square inch. The chamber 45 is connected to the combustion chamber 35 by a pressure supply conduit 47 having a check valve 48 therein, permitting gas flow from the combustion chamber 35 into the pressure chamber 45.

Operation of the apparatus shown in Figure 2 is as follows: Assuming that the magazine tube 41 is loaded with balls of projectile 42 and the chamber 45 is pressurized initially by some outside means, feeding for the first round into barrel 38, to some pressure which is higher than the minimum pressure in the combustion chamber 35 with both of the orifices or tubes 38 and 39 open, say a pressure of 3,100 pounds as is present in chamber 45 as determined by the regulating pressure valve 46, and that the hypergolic propellants are introduced into the combustion chamber at rates to maintain a slightly lower predetermined minimum pressure in the combustion chamber of say 3,000 pounds while both of the tubes 38 and 39 are open. The first ball 42 when released is forced downwardly into the gun barrel 38 by the 3,100 pounds pressure behind it, acting on the one way piston 43 and the column of balls 41—41. The gun barrel 38 up to now being under 3,000 per square inch minimum pressure. As soon as the lower ball 42 is forced into the gun barrel 38 by the excess 100 pound pressure the flow of gas out of the gun barrel 38 is interrupted and pressure in the combustion chamber 35 now raises to a much greater amount say about 6,000 pounds per square inch. This is because the propellant feed is constant and the orifice discharge area is reduced one-half by the blocking of the gun barrel by the ball 41. As soon as the ball is driven out of the gun barrel 38 by the maximum 5,000 per square inch built up pressure, gas can again flow out of both orifices or tubes 38 and 39 and the pressure in the combustion chamber 35 drops again to the original minimum value of about 3,000 pounds. This permits the feeding of the next ball into the gun tube 38 from the magazine 41 under the

excess 100 pound pressure in the pressure chamber 35 and the firing operation of the gun is repeated until the ball magazine is empty.

Although two specific embodiments of the invention have been described above and shown in the accompanying drawings, it will be understood that other embodiments and modifications will become apparent to those skilled in the art. Accordingly, the foregoing disclosure is intended to be illustrative and is not to be construed in a limiting sense as various modifications may be made without departing from the spirit of the invention as defined in the accompanying claims.

I claim:

1. In a hypergolic liquid propellant gun, an elongated combustion chamber having front and rear ends, a gun barrel projecting forwardly from the front end of the combustion chamber in communication therewith, a shell feeding magazine tube projecting rearwardly from the rear end of the combustion chamber in axial alignment with the gun barrel, in communication at its front end with the rear end of the combustion chamber, hypergolic propellant supply means including conduit means for supplying at least two hypergolic propellants separately into the combustion chambers at a predetermined rate to be burned therein to pressurize the combustion chamber, pressure operated means in said magazine tube for feeding shells from said magazine to be into the rear end of said gun barrel comprising a pressure conduit connected between the combustion chamber and the rear end portion of the magazine tube to pressurize the tube, a check valve in said pressure conduit, and a pressure regulator in communication with the rear end portion of the magazine tube to maintain the shell feeding pressure therein at a predetermined value during operation of the gun which is greater than the minimum pressure within the combustion chamber when the gun barrel is empty and less than the maximum pressure in the combustion chamber after the shell is introduced into the barrel and before the same is discharged therefrom.

2. In a hypergolic liquid propellant operated gun, a combustion chamber, a gun barrel projecting forwardly from the combustion chamber in communication therewith a projectile feeding magazine tube projecting rearwardly from the combustion chamber in axial alignment with the gun barrel and in communication with the combustion chamber for receiving a plurality of projectiles and feeding the same into the rear end gun barrel one at a time, an exhaust tube in communication with the combustion chamber intermediate the gun barrel and magazine tube and discharging in diametrically opposite directions to the gun barrel for absorbing recoil during discharge of projectiles from the gun barrel, a restricted discharge nozzle at the rear end of said exhaust tube plural hypergolic liquid propellant supply means including plural conduit means therefrom connected to the combustion chamber for continuously feeding hypergolic propellants separately into the combustion chamber at pressures in excess of the maximum combustion chamber pressure during operation of the gun, means for regulating the relative rates of feed of the hypergolic propellants into the combustion chamber to predetermine the maximum build up pressure therein when a projectile is introduced into the gun barrel to obstruct the combustion chamber discharge therefrom through the gun barrel and determine minimum pressure in the combustion chamber, gun barrel, and exhaust tube, after the projectile has been discharged from the gun tube and before another projectile is introduced into the gun barrel, pressure operated piston means in said magazine tube for progressively feeding projectiles from the magazine tube into the rear end of the gun barrel including a pressure chamber and piston member in the rear end of the magazine tube in communication with the combustion chamber and a pressure regulator in the magazine tube pressure chamber for maintaining pressure in the magazine tube behind said piston means above said mini-

mum combustion chamber pressure and below said maximum combustion chamber pressure, and means in said magazine tube for holding the projectiles therein against rearward movement during the time pressure in the combustion chamber exceeds pressure in the pressure chamber.

3. In a liquid propellant operated repeating gun, a gun barrel, a combustion and pressure chamber connected to the rear of the gun barrel in communication therewith, a projectile feeding magazine tube extending rearwardly in spaced axial alignment to the rear end of the gun barrel with its front end opening into said combustion and pressure chamber, said magazine tube being adapted to receive a plurality of projectiles therein, means in the magazine tube for preventing rearward movement of the projectiles therein, a closure at the rear end of the magazine tube, pressure regulating means in communication with the rear end of the magazine tube, a piston member disposed in the magazine tube for projectile feeding engagement with the rearmost projectile in the magazine tube, stop means in the magazine tube limiting rearward movement of the piston member, a pressure supply conduit connected between the combustion and pressure chamber and the rear portion of the magazine tube intermediate said piston and the rear end closure, check valve means in said pressure conduit to permit pressure flow from the combustion chamber into the magazine tube rear portion, a pair of counter-recoil exhaust tubes connected to the (opposite sides of) combustion and pressure chamber and extending rearwardly at opposite sides of the magazine tube in parallel spaced relation thereto, restricted exhaust nozzle means at the rear ends of the exhaust tubes facing rearwardly, a pair of liquid propellant supply conduits connected to the interior of the combustion chamber in spaced relation to each other for supplying liquid hypergolic propellants separated into the combustion chamber, means for regulating the relative rates of flow of the propellants into the combustion chamber to determine the maximum pressure therein when the gun barrel is closed by the introduction of a projectile into the gun barrel from the magazine tube, and to determine the minimum pressure in the combustion chamber when the gun barrel is empty, a pressure delivery conduit connected at one end in communication with the interior of the gun barrel adjacent its rear end, just forwardly of the position occupied by a projectile when introduced in the rear end of the gun barrel, a pressure cylinder having a piston therein, said pressure delivery conduit being connected to the pressure cylinder at one side of the piston, check valve means in the pressure delivery conduit for admitting pressure from the gun barrel into the pressure cylinder when the pressure delivery conduit is uncovered by the passage of a projectile forwardly from the rear end of the gun barrel, a pressure supply conduit connected at one end to the combustion chamber and at its other end to the pressure cylinder at the other side of the piston therein, and control valve means in the pressure delivery conduit for controlling the pressure from the pressure cylinder into said combustion and pressure chamber.

4. In a liquid propellant operated repeating gun, a gun barrel having a breach end for receiving projectiles to be discharged through the barrel, a projectile supply magazine tube for the gun barrel disposed in rearwardly spaced relation to the breach end of the gun barrel in axial alignment with the gun barrel, and adapted to contain a supply of projectiles, an enlarged pressure chamber connected to the breach end of the gun barrel and the front end of the magazine tube in communication respectively with the barrel and tube, a plurality of exhaust recoil tubes in communication with the pressure chamber and extending rearwardly therefrom in parallel relation to the magazine tube, the combined cross sectional exhaust area of said exhaust tubes being substantially equal to the cross sectional area of the interior of the gun barrel, exhaust nozzles at the rear ends of the exhaust tubes discharging rearwardly, a combustion chamber surrounding the inner end of the magazine tube, the forward end of said magazine tube having pressure discharge ports formed therethrough to establish communication between the combustion chamber and the pressure chamber through the forward end of the magazine tube, projectile holding means disposed in the magazine tube adjacent its forward end for engaging and holding a projectile in the magazine tube against rearward movement when the projectile is moved to a position adjacent the forward end of the tube, rearwardly of the ports in the tube, a piston member movable in the tube for advancing the projectiles toward the front end of the tube, stop means in the tube for engagement with the piston to prevent rearward movement thereof, pressure regulator means forming a closure for the rear end of the tube, a pressure supply conduit connected in communication with the combustion chamber at one end and connected at its other end in communication with the interior of the magazine tube intermediate the piston and the pressure regulator, check valve means in the pressure supply conduit opening toward the magazine tube connected end of the conduit, separate hypergolic liquid supply conduits disposed in communication with the interior of the combustion chamber for feeding hypergolic liquid propellants separately into the combustion chamber and regulating means in said separate conduits for regulating relative the rates of introduction of the hypergolic liquid propellants into the combustion chamber.

5. Apparatus as claimed in claim 4 including a pressure cylinder having a piston therein, a pressure supply conduit connected at one end to the pressure cylinder at one side of the piston, and connected at its other end in communication with the interior of the gun barrel through a port in the gun barrel located in advance of the position of a projectile when introduced into the projectile receiving end, said port being uncovered by the forward movement of the projectile from the projectile receiving end to establish communication between the last mentioned pressure supply conduit and the pressure chamber, a check valve in said last mentioned pressure supply conduit opening toward the pressure cylinder, a pressure supply conduit connected between the pressure cylinder at the other side of the piston and the interior of the combustion chamber, and valve control means in the last mentioned conduit for controlling pressure from the pressure chamber to the combustion chamber.

6. Apparatus as claimed in claim 5 in which the pressure regulator means for the pressure in the rear of the magazine tube in back of the piston therein comprises means for maintaining a differential pressure on the piston just mentioned exceeding the pressure in the pressure chamber when the gun barrel is empty and less than the pressure in the pressure chamber when the gun barrel receives a projectile in its receiving end.

7. In a liquid propellant gun of the hypergolic type, a combustion chamber, a gun barrel extending forwardly therefrom with its rear end in communication with said combustion chamber, recoil absorbing exhaust tube means extending rearwardly from the combustion chamber in diametrically opposite direction from the gun barrel and in communication with the interior of the combustion chamber, exhaust nozzle means at the rear ends of the exhaust tube means discharging rearwardly, the cross sectional exhaust area of said recoil absorbing tube means and said gun barrel being substantially equal, hypergolic fuel and oxidizer liquid propellant means for introducing liquid hypergolic fuel and oxidizer propellants into the combustion chamber to be burned therein to create a predetermined minimum combustion chamber pressure when the gun barrel is empty of projectiles and causing a predetermined maximum combustion chamber pressure where the gun barrel is blocked by a projectile therein, a projectile feeding magazine tube connected to

the gun barrel through a projectile introducing port in the gun barrel adjacent the rear end of the gun barrel, a piston in said magazine tube for feeding projectiles from the magazine tube into the gun barrel one at a time, projectile holding means in said magazine tube disposed rearwardly of projectiles introduced therein for preventing rearward projectile movement of projectiles in the magazine tube, an enlarged pressure chamber connected to the magazine tube in rear of the piston therein, a pressure regulator valve connected to the enlarged pressure chamber maintaining a maximum operating pressure in said enlarged pressure chamber greater than the minimum combustion chamber when the gun barrel is empty and less than the combustion chamber pressure when the gun barrel is blocked by a projectile from the magazine tube, a pressure supply conduit connected at one end with the interior of the combustion chamber and at its opposite end to the interior of the pressure chamber, and check valve means in said pressure supply conduit, opening toward said pressure chamber.

8. In a hypergolic liquid propellant gun, a gun barrel, a combustion chamber in communication with the rear end of the gun barrel, recoil absorbing means comprising an exhaust tube in communication with said combustion chamber and extending therefrom in a direction rearwardly of the direction of the gun barrel having a restricted exhaust passage, a projectile magazine tube having a projectile delivery end in communication with the combustion chamber and the rear end portion of the gun barrel at its projectile delivery end for guiding projectiles from the magazine tube into the said rear end portion of the gun barrel, piston means in the magazine tube in rear of the projectiles when introduced in the magazine tube for advancing the projectiles toward the delivery end, a pressure chamber in communication with the interior of the magazine tube rearwardly of the piston member therein for supplying pressure to advance the projectiles therein into the gun barrel, maximum pressure regulating means for said pressure chamber, means to supply hypergolic liquids separately into said combustion chamber to be mixed and spontaneously burned therein to pressurize the combustion chamber, a pressure supply conduit connected from the combustion chamber to the pressure chamber to pressurize the pressure chamber from the combustion chamber and check valve means in said pressure supply conduit opening toward the said pressure chamber, whereby when the pressure in the combustion chamber increases during the discharge of a projectile through the barrel and exceeds the pressure in the pressure chamber, combustion chamber pressure is admitted to the pressure chamber to increase the pressure chamber pressure; and upon discharge of the projectile from the barrel, the barrel is vented and thereby reduces the combustion chamber pressure below the regulated pressure chamber pressure, and the higher pressure in the pressure chamber at that time is operative on the piston means to advance the projectiles in the magazine tube to feed a fresh projectile into the barrel to charge the gun barrel and interrupt the vented discharge of the hypergolic combustion gases from the barrel and combustion chamber to build up pressure in the combustion chamber in excess of the pressure chamber pressure for projecting the fresh introduced projectile from the barrel and recharging the pressure chamber.

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[54] LIQUID FUEL OPERATED AUTOMATIC WEAPONS

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[22] Filed: April 26, 1971

[21] Appl. No.: 137,287

[52] U.S. Cl. ....89/7, 89/33 CA, 89/161
[51] Int. Cl. F41f 1/04
[58] Field of Search ....89/7, 1, 161, 33 R, 33 CA, 89/33 BB

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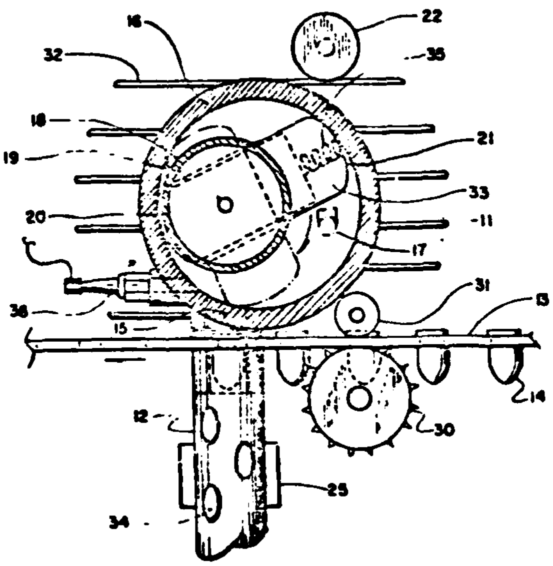
[57] ABSTRACT

The automatic weapon has a compression chamber with a power outlet port aligned with a reciprocating barrel and an intake port aligned with a carburetor. A belt carrying a plurality of projectiles is fed between the reciprocating barrel and the power outlet port. A shaft driven rotor and vane are offset positioned within the compression chamber. The barrel, belt and rotor are synchronized so that carbureted fuel is compressed and ignited when the barrel has forced the belt to sealably engage the power outlet port with a projectile positioned in the barrel.

10 Claims, 5 Drawing Figures



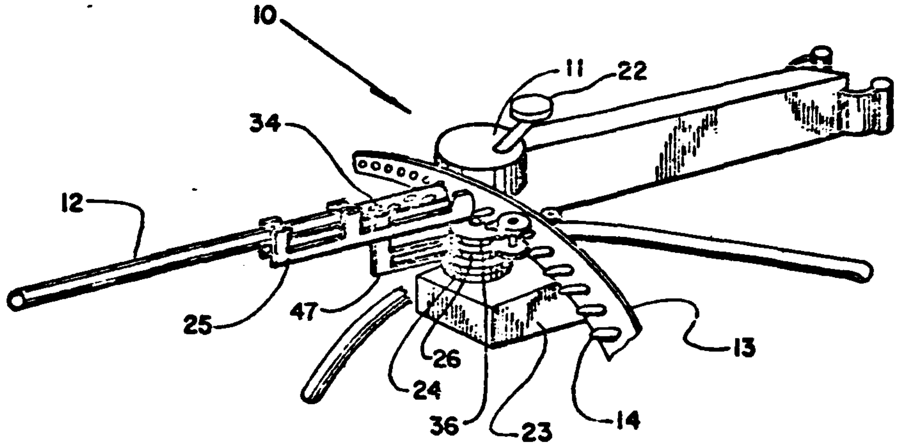


Fig. 1

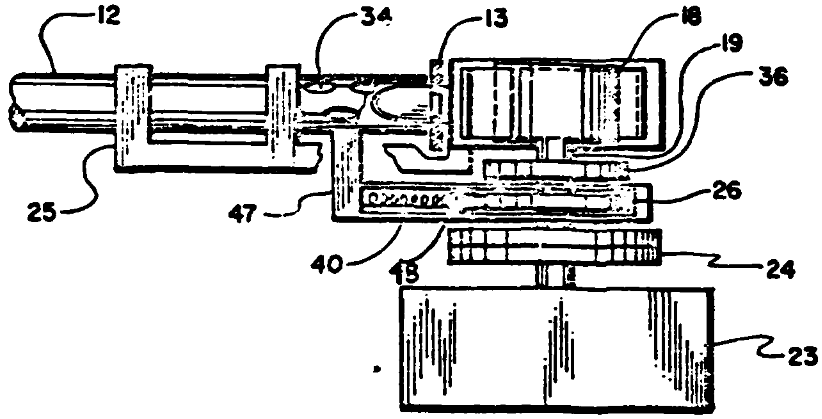


Fig. 2

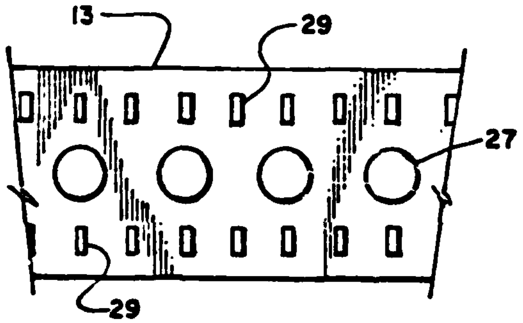


Fig. 5

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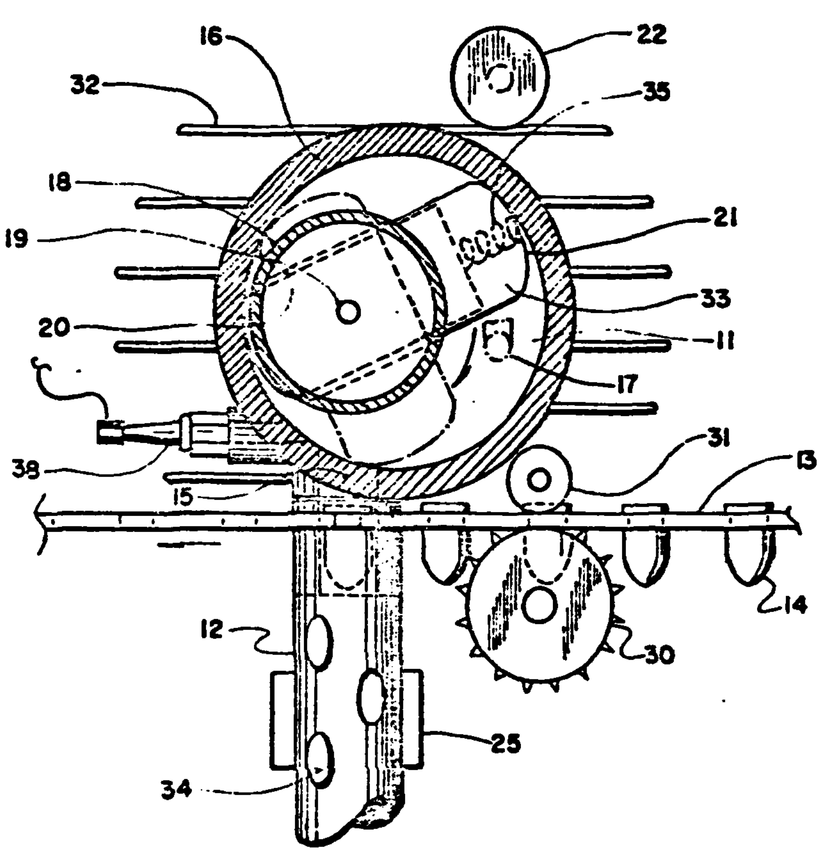

Fig. 3

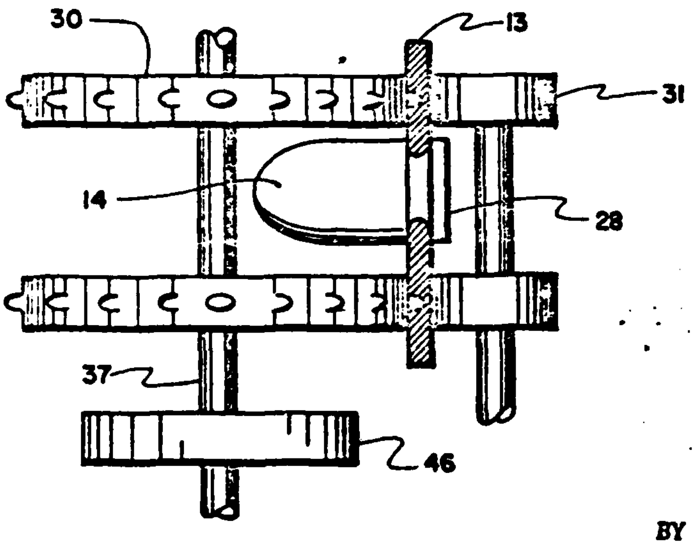

Fig. 4

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LIQUID FUEL OPERATED AUTOMATIC WEAPONS

My invention relates to an article of ordinance and, more particularly, to a liquid fuel operated automatic weapon, such as a machine gun.

The standard automatic weapon is operated by detonation of gun powder in a shell which propels a projectile secured thereto.

My invention eliminates the gun powder, the shell and the detonator, thereby rendering the automatic weapon safer, more transportable and, in general, far more versatile than existing automatic weapons.

In the accompanying drawings, I have shown one preferred embodiment of my invention in which:

FIG. 1 is a schematic of my automatic weapon;

FIG. 2 is a partial broken away view showing the operating mechanisms;

FIG. 3 is a plan view partly broken away to show the operating mechanism;

FIG. 4 is an exploded view of the belt, projectile and drive means; and

FIG. 5 is a plan view of the belt.

My automatic weapon will be generally referred to as machine gun 10, although it will be recognized that various types of automatic weapons in addition to machine guns may be constructed in accordance with my invention.

Machine gun 10 includes a compression chamber 11, a reciprocating barrel 12 and a belt 13 carrying the projectiles 14. The chamber 11 has a cylindrical inner surface formed by wall 16. Communicating with chamber 11 through wall 16 is intake port 17, power outlet port 15 and spark plug 38 which extends through wall 16 into the chamber 11 at a point substantially adjacent the power outlet port 15. Chamber 11 is air-cooled by fins 32 in a known manner, FIGS. 1 and 3.

A rotor 18 is mounted on a shaft 19 and is positioned in the chamber so that shaft 19 is substantially in alignment with the power outlet port 15. However, the rotor 18 is offset in the chamber 11 so that it is substantially adjacent the interior wall 16. Rotor 18 has a slideway 20 above the shaft 19 into which an extensible vane 21 is slidably positioned. Vane 21 is extensible by means of a spring load 35 which forces separate end section 33 outward to sealably engage the interior of wall 16 as vane 21 rotates along with the rotor 18. The slidable engagement of vane 21 in slideway 20 of rotor 18 and the extensibility of end section 33 permits a constant and continuing sealable relationship between the interior of wall 16 and the vane 21 at both ends of the vane 21, FIGS. 2 and 3.

A carburetor 22 is connected to the intake port 17 and provides a carbureted liquid fuel, such as gasoline, thereto. The air and fuel means feeding the carburetor 22 are not shown and do not form a part of this invention.

Shaft 19 extends downward to and is driven by motor 23. Motor 23 may be a gasoline operated motor, an electrical motor or any other type which will rotate shaft 19. Friction clutch 24 is positioned along shaft 19 in the standard manner to permit engagement and disengagement of shaft 19 to motor 23, FIG. 2.

The reciprocating barrel 12 is supported by barrel rest 25 which connects to a stationary member such as compression chamber 11, FIG. 2. Barrel 12 is positioned in alignment with the power outlet port 15 which is built up to have its forward face parallel to the rear face of barrel 12, FIG. 3. Barrel 12, which is free to reciprocate within barrel rest 25, is operably connected by barrel bracket 47 to the cam 26 on shaft 19. This connection is formed by cam 26 contacting roller 48 which is connected to the spring 40 positioned between roller 48 and bracket 47 to cause the desired reciprocation of the barrel 12. Cam 26 operates to reciprocate barrel 12 in synchronization with rotor 18 as will be explained in detail hereinafter. Barrel 12 includes a plurality of exhaust ports 34 therealong. Because of rapid firing, the barrel should be easily replaceable, but this can be accomplished by standard mounting means, FIGS. 1–3.

The projectile 14 is snugly held onto belt 13 through a frictional push fit arrangement in holes 27 which extend along the length of belt 13 in aligned relationship. The projectile 14 is cone-shaped at its forward end in standard fashion and has a rearward retaining flange 28 to hold it in place in right angle relationship to belt 13. The belt 13 also contains aligned drive slots 29 along the belt edges. The belt must be made of a material which can serve as a seal for a single use and which will not be disrupted by the residual heat, FIGS. 1, 2, 4 and 5.

A drive sprocket 30, the teeth of which engage the slots 29 of belt 13, is positioned to drive the belt 13 between the power outlet 15 and the barrel 12. An idler sprocket 31 positioned on the opposite side of belt 13 from the drive sprocket 30 maintains the belt 13 in cooperation with the drive sprocket 30 and in proper alignment for feeding. Both the drive sprocket 30 and the idler 31 are spooled to engage the slots 29 of the belt while at the same time maintaining clearance for the projectile 14. The drive sprocket 30 is connected by shaft 37 to a timing linkage formed by linkage means 46 and cam 32 positioned along shaft 19. Timing linkages are well known in the art and the particular type of timing linkage does not form a part of my invention. The belt 13 is operated in synchronization with the reciprocation of the barrel 12 and the rotation of rotor 18 and is timed to be stationary when the barrel 12 is in a closed position, FIGS. 2 and 4.

My machine gun works as follows. The carbureted fuel enters the compression chamber 11 through the intake port 17. The carbureted fuel is then compressed within the chamber 11 by the vane 21 which rotates with rotor 18 to reduce the effective space between the vane 21 and rotor 18 and the chamber wall 16. This reduction in space results from the offset position of rotor 18 with respect to wall 16. When the carbureted fuel has been adequately compressed, the spark plug operated by a magneto (not shown) ignites the mixture. At this time, the barrel 12 is in its closed position so as to engage the belt 13 which, in turn, sealably engages the power outlet 15 in the chamber wall 16. As stated hereinbefore, the timing linkage operates so that the belt is stationary in position when the barrel 12 reaches its closed position. As explosion takes place, the projectile, which is aligned in front of the power outlet 15 and within the barrel 12, is propelled outward. The exhaust gases exit the barrel through the exhaust ports 34.

Continued rotation of shaft 19 opens the barrel 12 and the next projectile 14 on belt 13 is positioned in alignment with power outlet 15. While this is taking place, the next charge of carbureted fuel has been drawn into the chamber 11 by the vacuum created by the moving vane. The firing rate is, therefore, 2 times for every revolution of the shaft 19. Therefore, if shaft 19 is driven at 2,500 rpm, 5,000 rounds/min. can be fired. The rate of fire is controllable by gearing down the motor 23 to control the revolutions per minute of the shaft 19. Clutch 24 is employed to engage or disengage the shaft 19 and motor 23 and thereby control the firing of the weapon.

I claim:

1. A liquid fuel operated automatic weapon including:

A. a compression chamber having an intake port and a power outlet port;

B. a carburetor means connected to the intake port to supply carbureted fuel thereto;

C. compression means within the compression chamber to place the carbureted fuel in a compressed state in the area of the power outlet port;

D. ignition means cooperating with the chamber to fire the carbureted fuel;

E. reciprocating barrel means positioned in operational alignment with the power outlet port;

F. belt means having a plurality of aligned projectiles secured thereto;

G. feed means connected to the belt means to feed the belt between the barrel and the power outlet port; and

H. synchronizing means connecting to the barrel and the feed means to position a projectile in line with the power outlet port and the barrel against the belt means to sealably engage the power outlet port when the ignition means fires.

2. The automatic weapon of claim 1 wherein the compression means includes a shaft driven rotor offset positioned adjacent an interior compression chamber wall and an adjustable vane cooperating with the rotor and the chamber wall to compress the carbureted fuel therebetween.

3. The automatic weapon of claim 2 wherein the rotor has a slideway therethrough and the vane is positioned in the slideway, said vane being extensible to sealably engage the chamber wall at both ends of the vane at all times.

4. The automatic weapon of claim 3 wherein the extensible vane includes a spring loaded outer section which is continually forced outward to sealably engage the chamber wall.

5. The automatic weapon of claim 2 wherein the reciprocating barrel means includes a plurality of exhaust ports therein.

6. The automatic weapon of claim 2 wherein the belt means includes a plurality of aligned holes which frictionally engage the projectiles to secure them thereto, said projectiles having a cone-shaped forward section and a flanged rearward section to maintain the projectile on the belt normal thereto.

7. The automatic weapon of claim 2 wherein the feed means includes a drive sprocket and an idler sprocket positioned on opposing sides of the belt means.

8. The automatic weapon of claim 2 wherein the synchronizing means includes two cams positioned on the shaft which rotates the rotor, one cam connecting to the barrel to cause reciprocation thereof and the other cam connecting to the feed means as part of a timing linkage.

9. The automatic weapon of claim 2 wherein a motor means connects to the shaft, said motor means including a clutch to engage the shaft.

10. The automatic weapon of claim 7 wherein the drive sprocket is in operable engagement with the shaft which drives the rotor through a timing linkage.

* * * * *

United States Patent [19]

Elmore et al.

[11] **4,062,266**

[45] **Dec. 13, 1977**

[54] **LIQUID PROPELLANT MODULAR GUN INCORPORATING DUAL CAM OPERATION AND INTERNAL WATER COOLING**

[76] Inventors: **Lester C. Elmore,** 125 Bear Gulch Drive, Portola Valley, Calif. 96122; **Thomas M. Broxholm,** deceased, late of Palo Alto, Calif. by Anne K. Broxholm, administratrix, 4194 Oak Hill Drive, Palo Alto, Calif. 94306

[21] Appl. No.: **616,822**

[22] Filed: **Sept. 25, 1975**

[51] **Int. Cl.**[2] **F41F 1/04**

[52] **U.S. Cl.** .... **89/7;** 89/1 E; 89/11

[58] **Field of Search** .... 89/7, 9, 11, 1 E, 14 A, 89/33 C, 28

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Primary Examiner—David H. Brown
Attorney, Agent, or Firm—Donald C. Feix

[57] **ABSTRACT**

A liquid propellant modular gun has a slim profile and is constructed for wide latitude in gun cluster configuration.

The modular gun has a stationary barrel and is externally driven and cam operated by a drive cam and a control cam.

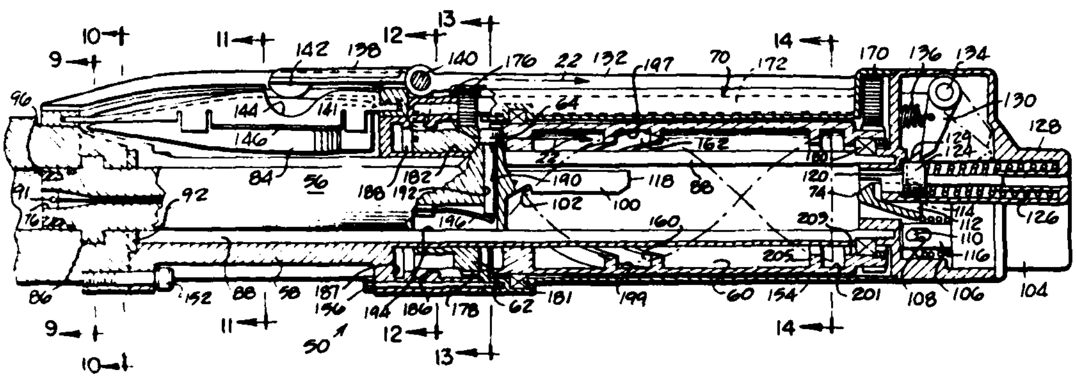
The drive cam has one internal spiral cam track for driving the bolt forward to a projectile firing position and another internal spiral cam track for driving the bolt rearward to a projectile loading position.

The control cam is mounted for rotation at the forward end of the drive cam and controls the injection of liquid propellant into the combustion chamber and an electrical igniter.

A water injection mechanism is also associated with the control cam for injecting a small amount of water into the combustion chamber after the firing of each round to cool the combustion chamber structure by internal water cooling. The water injection mechanism is also effective to purge propellant from the combustion chamber in the event of a misfire.

The bolt is rotated to a locked position at the forward end of its travel where locking lugs on the bolt are engaged with mating lugs on the barrel so that all breach loads caused by chamber pressure are carried through the barrel rather than the receiver. This permits the receiver to be made quite light.

43 Claims, 46 Drawing Figures



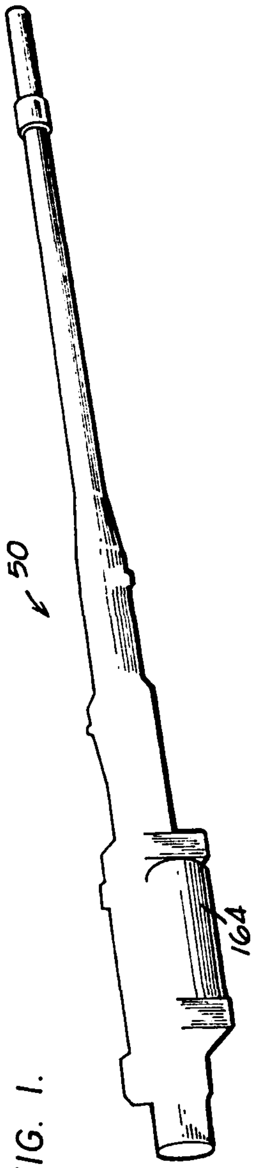


FIG. 1.

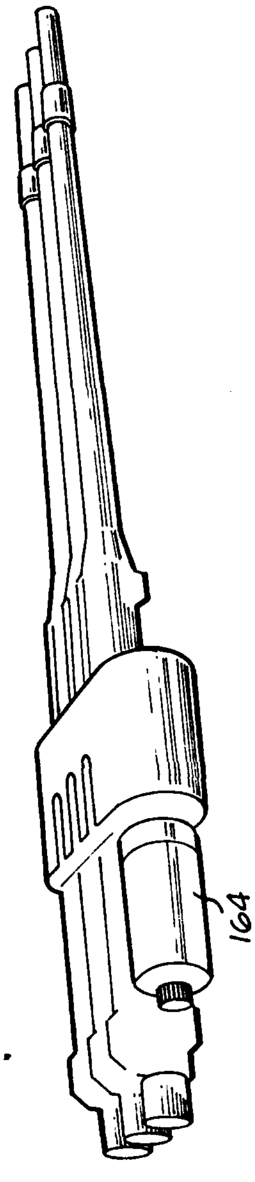


FIG. 2.

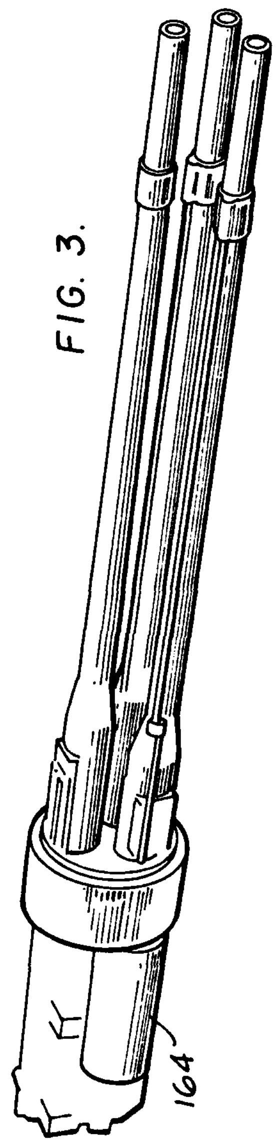


FIG. 3.

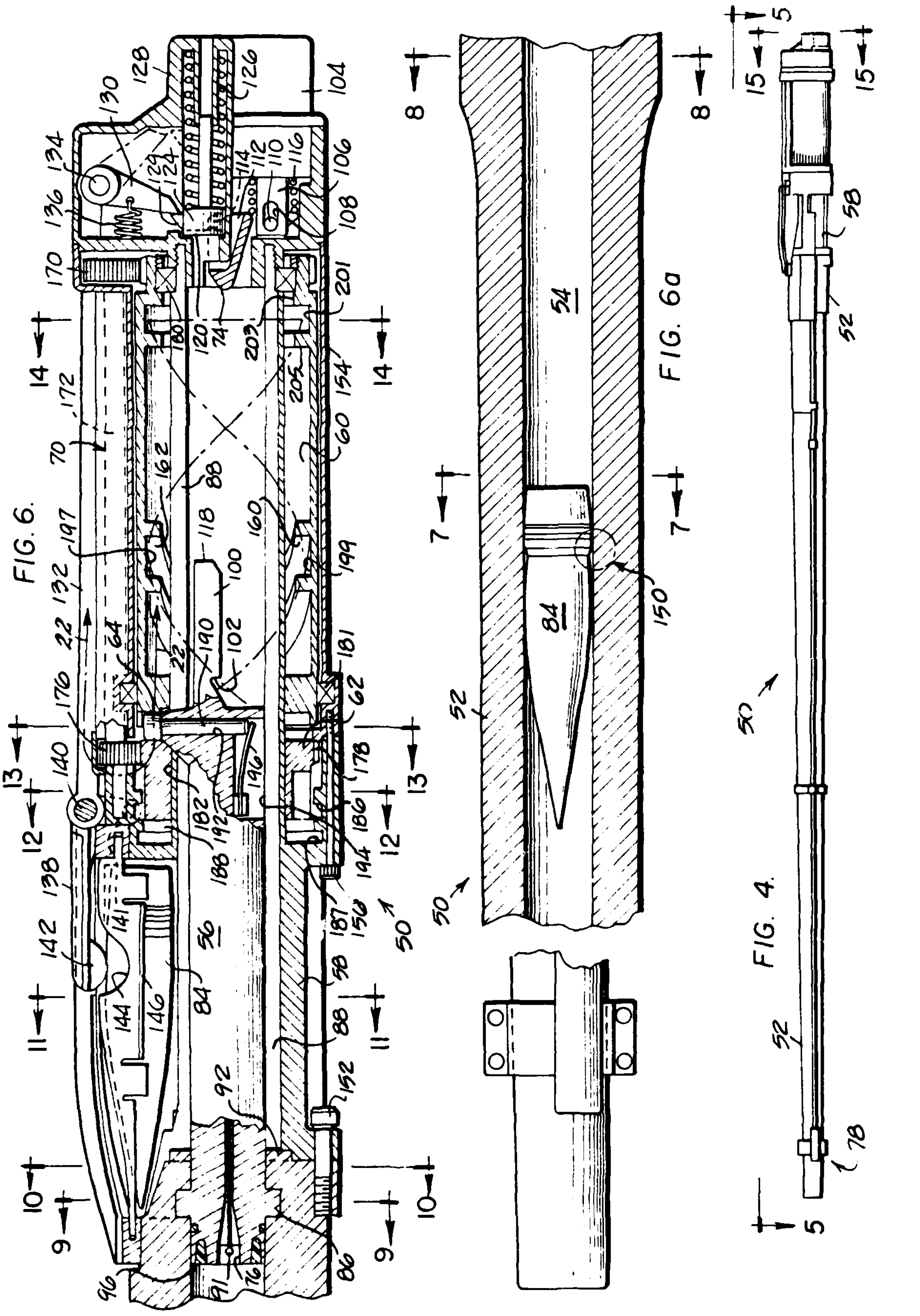


FIG. 6.

FIG. 6a

FIG. 4.

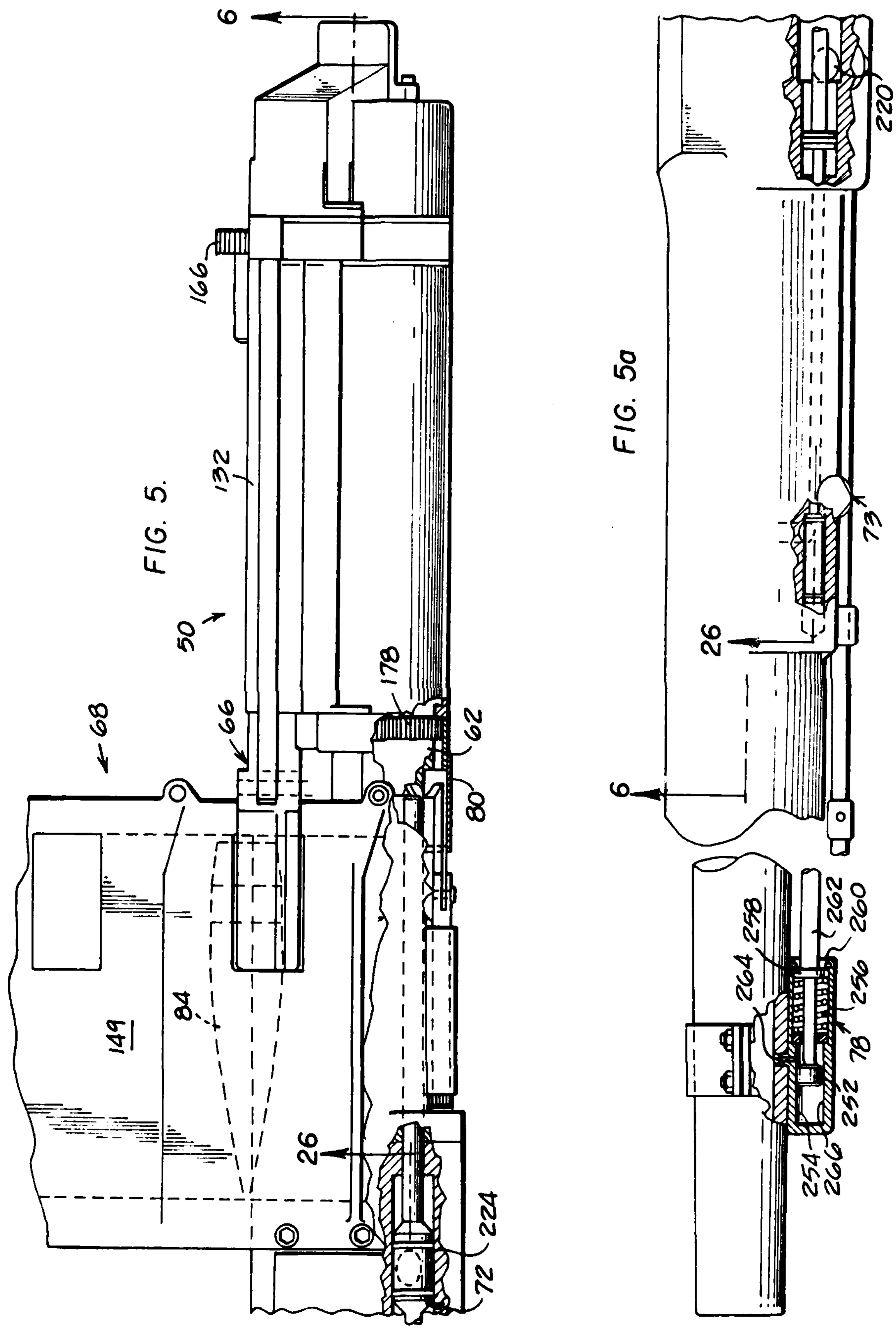


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FIG. 5.

FIG. 5a

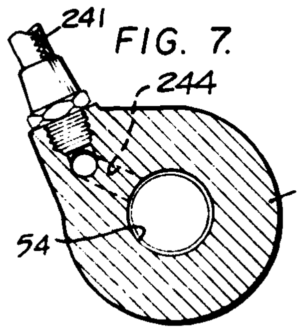


FIG. 7.

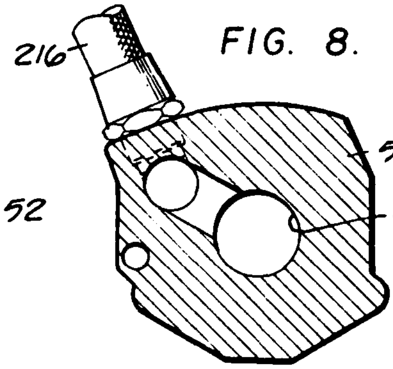


FIG. 8.

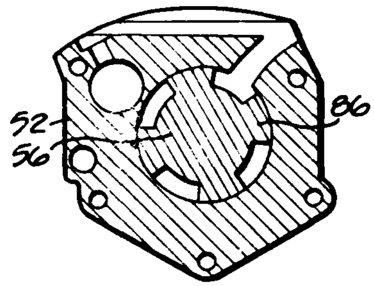


FIG. 9.

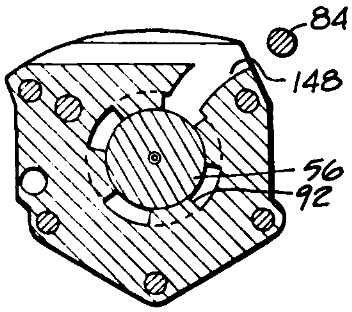


FIG. 10.

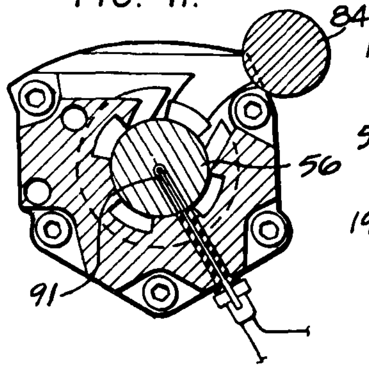


FIG. 11.

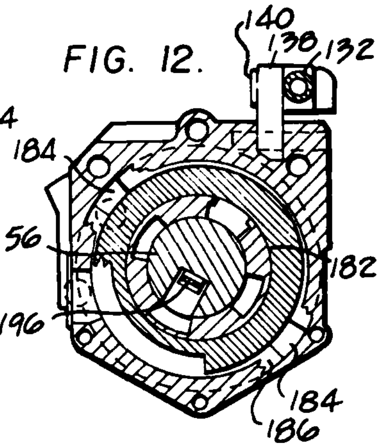


FIG. 12.

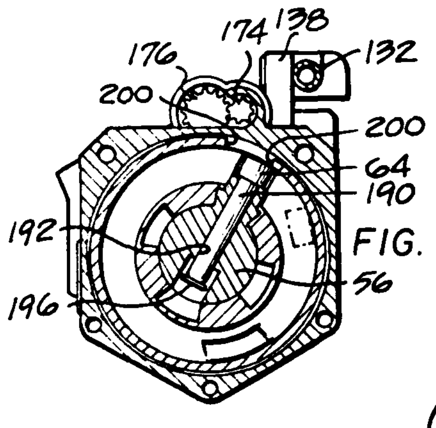


FIG. 13.

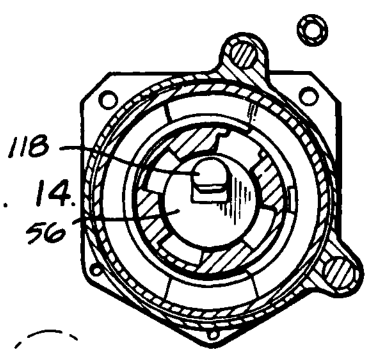


FIG. 14.

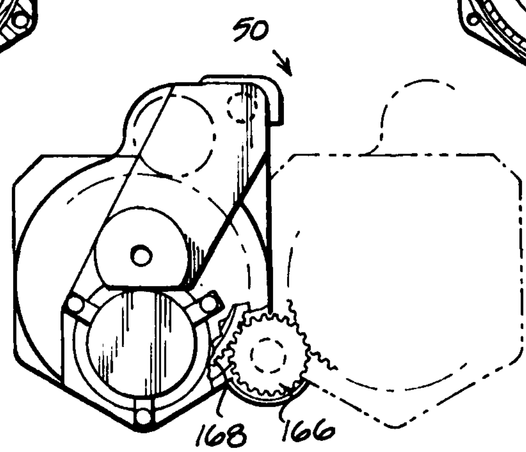


FIG. 15.

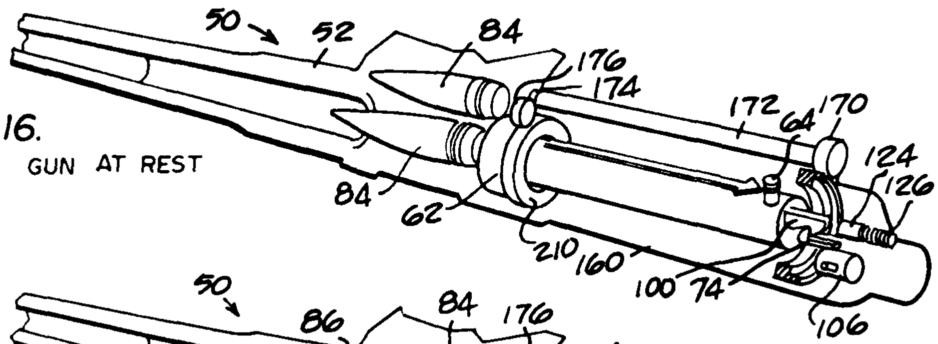


FIG. 16.
GUN AT REST

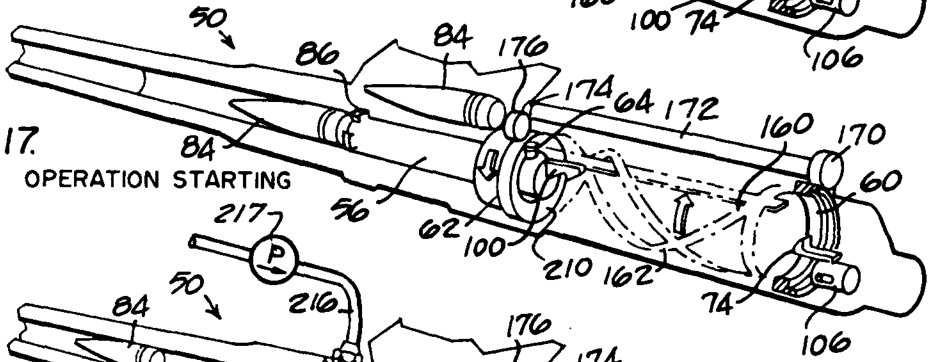


FIG. 17.
OPERATION STARTING

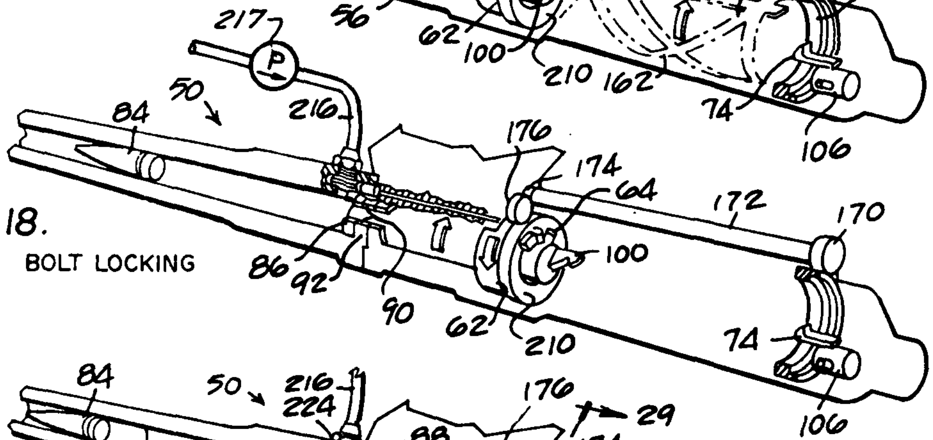


FIG. 18.
BOLT LOCKING

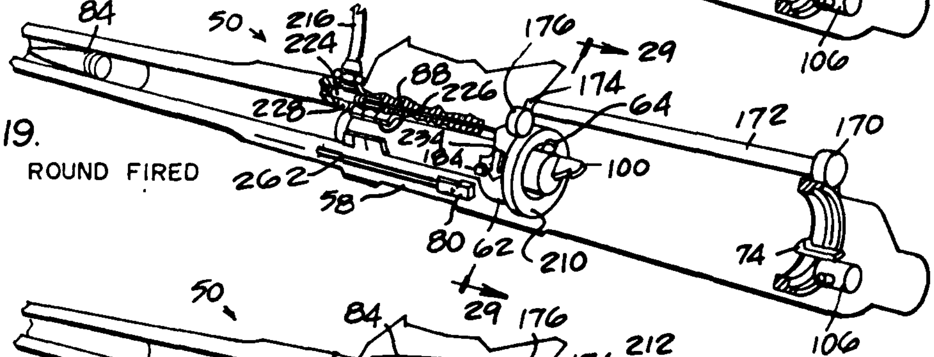


FIG. 19.
ROUND FIRED

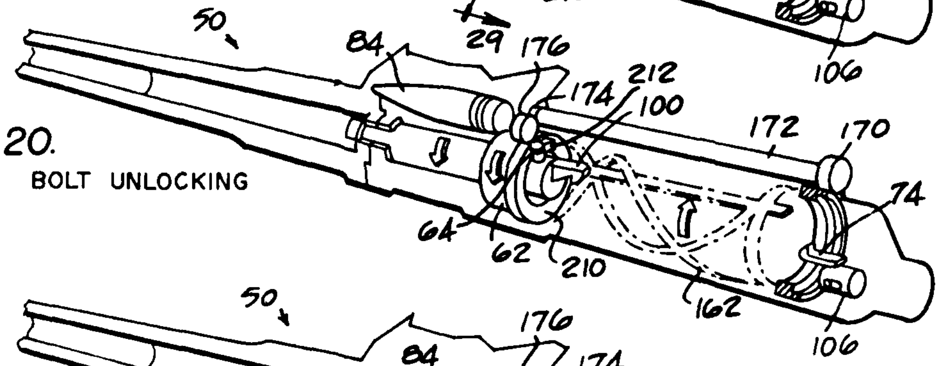


FIG. 20.
BOLT UNLOCKING

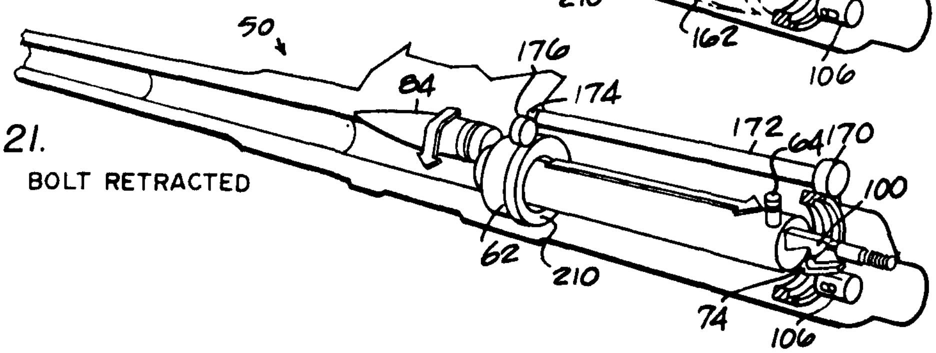


FIG. 21.
BOLT RETRACTED

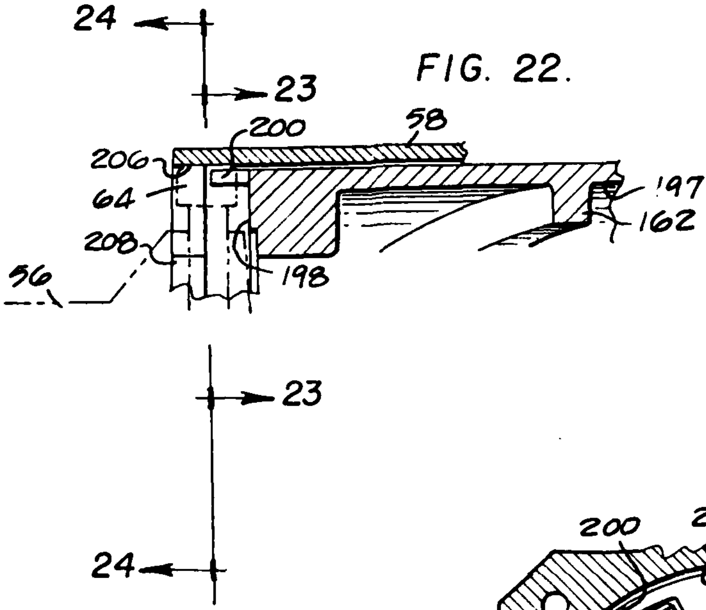


FIG. 22.

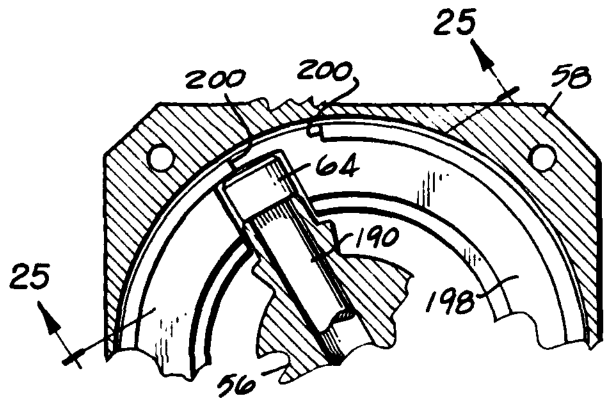


FIG. 23.

FIG. 24.

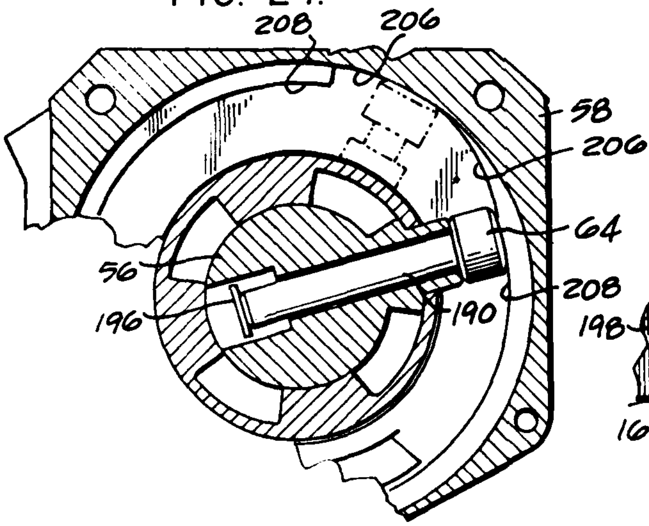


FIG. 25.

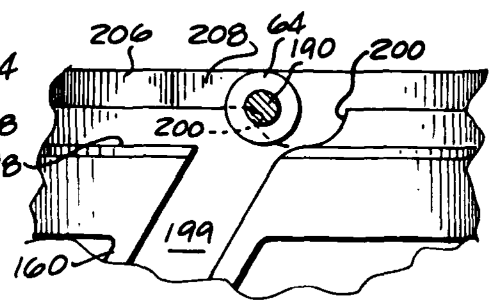


FIG. 26. FIRING POSITION

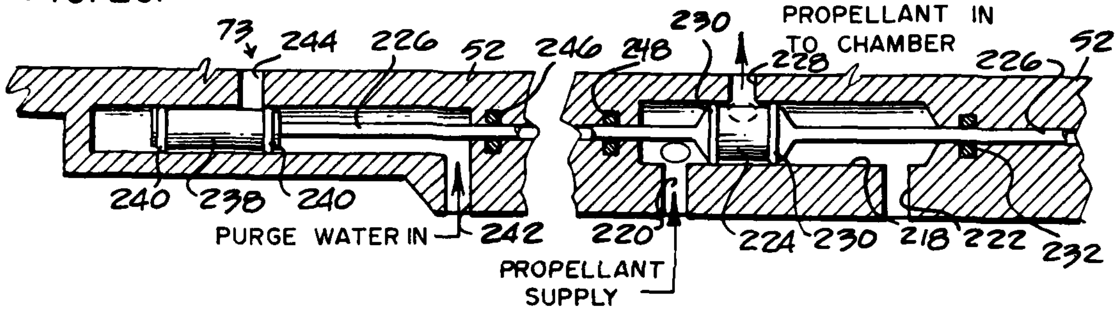


FIG. 27. PROPELLANT LOADING POSITION

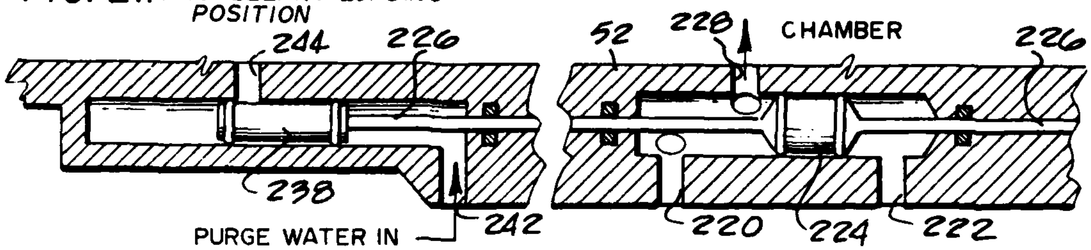
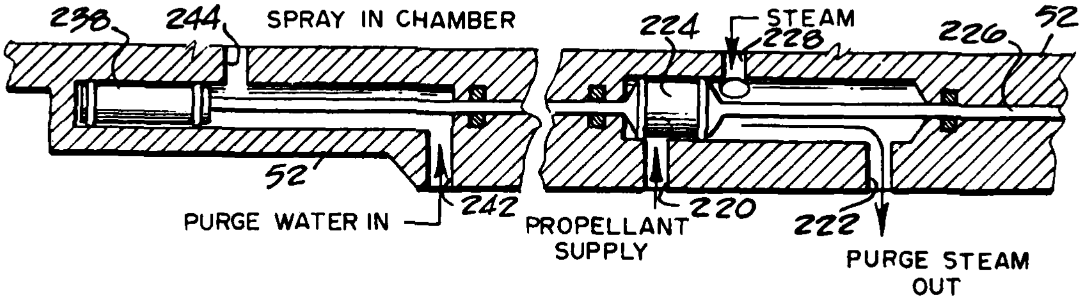


FIG. 28. EMERGENCY PURGE OR COMBUSTION CHAMBER COOLING



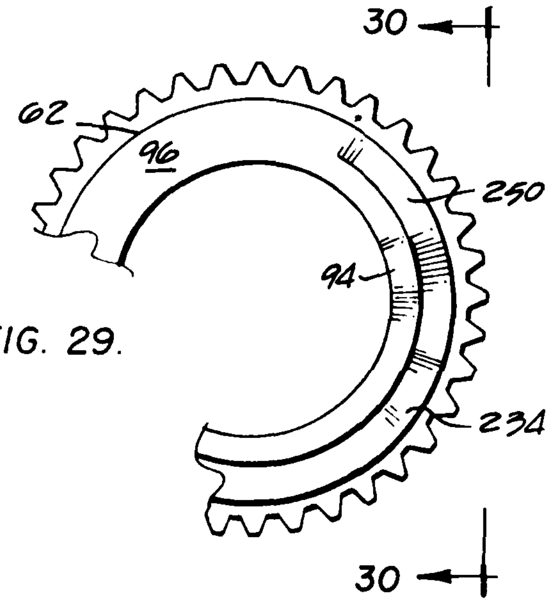


FIG. 29.

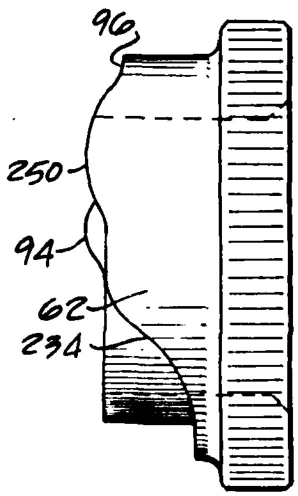


FIG. 30.

FIG. 31.

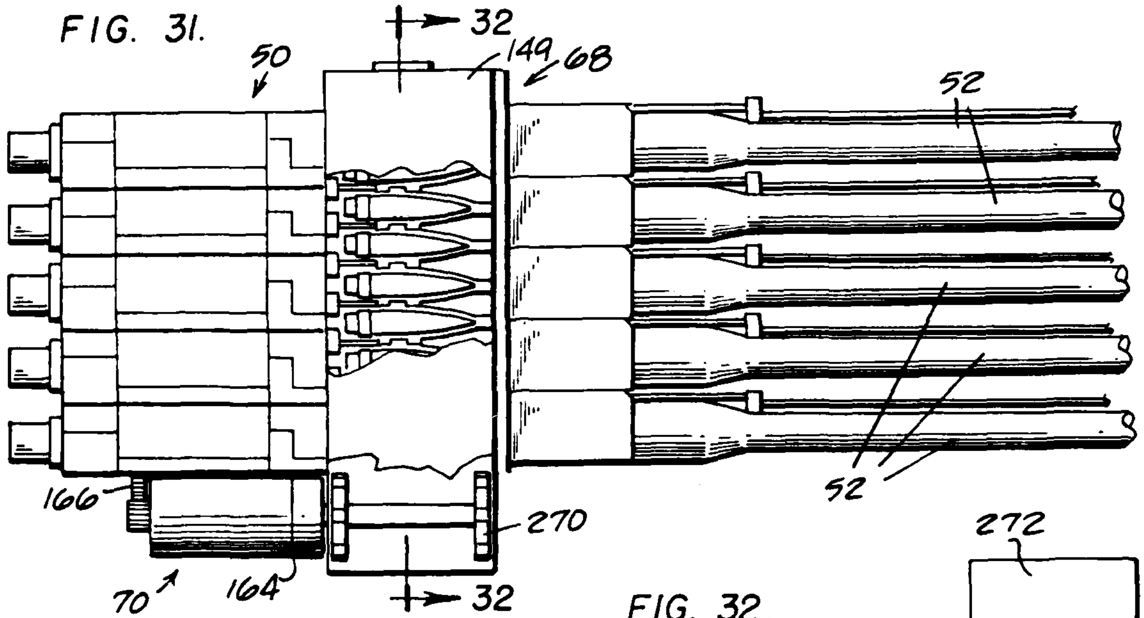


FIG. 32.

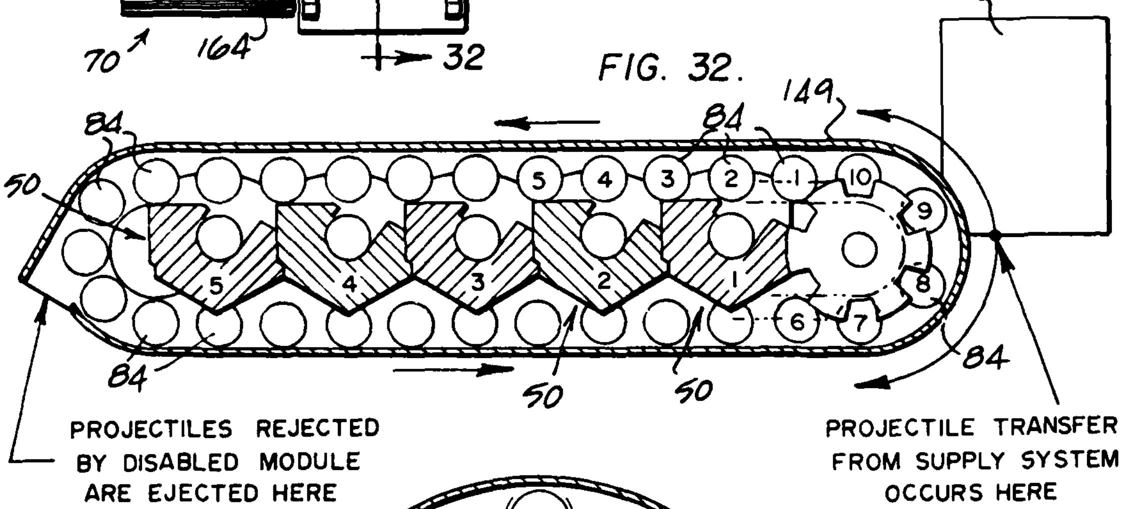
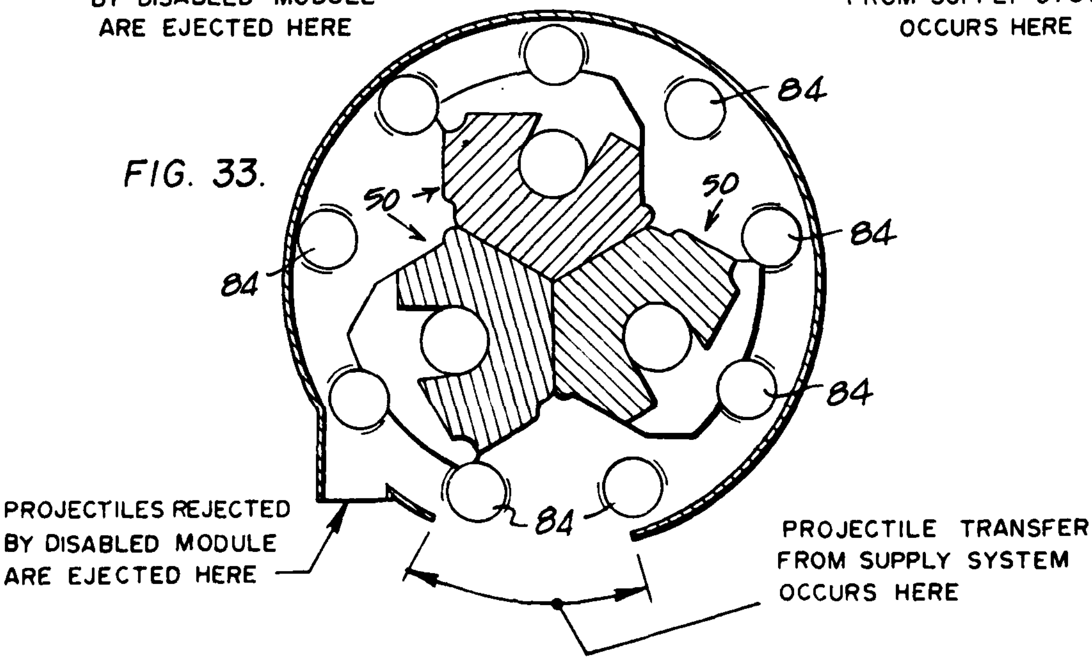


FIG. 33.



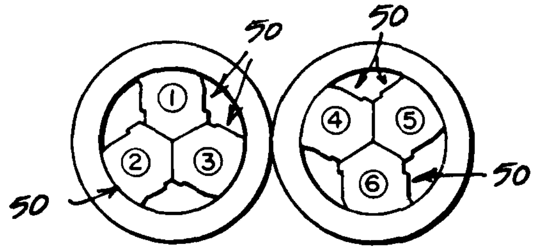


FIG. 34.

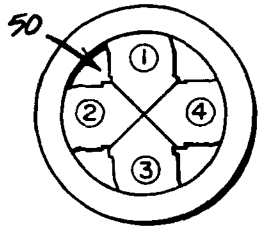


FIG. 35.

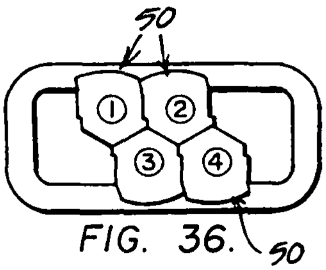


FIG. 36.

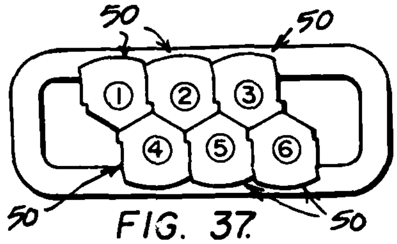


FIG. 37.

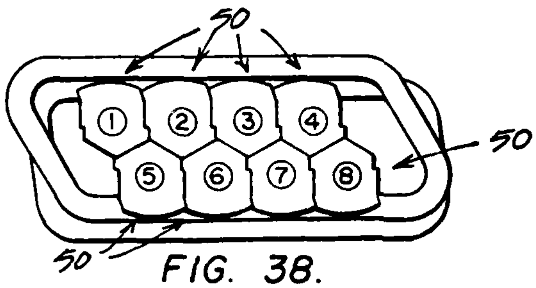


FIG. 38.

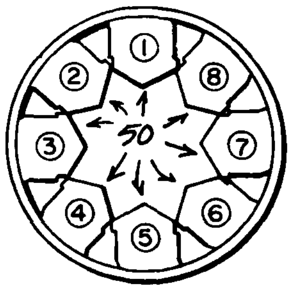


FIG. 39.

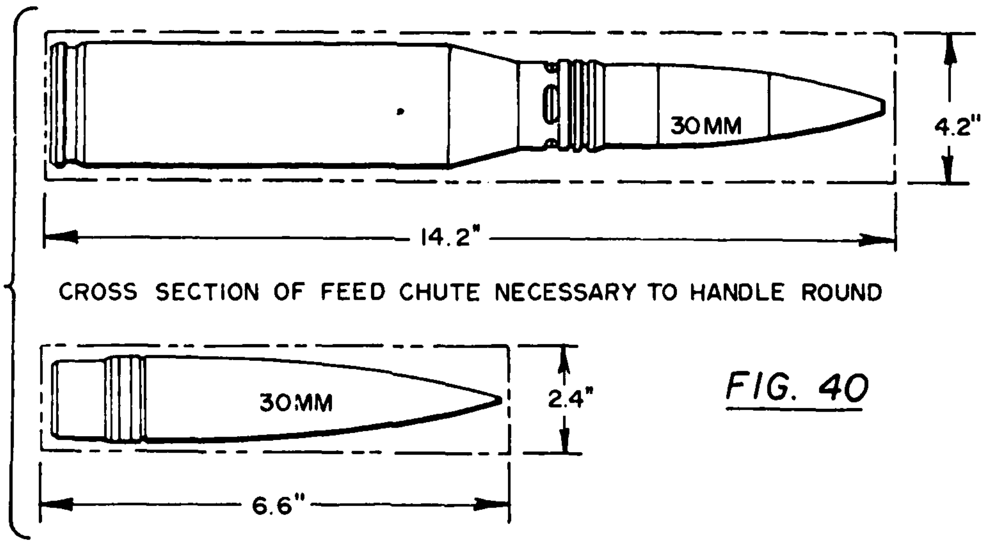


FIG. 40

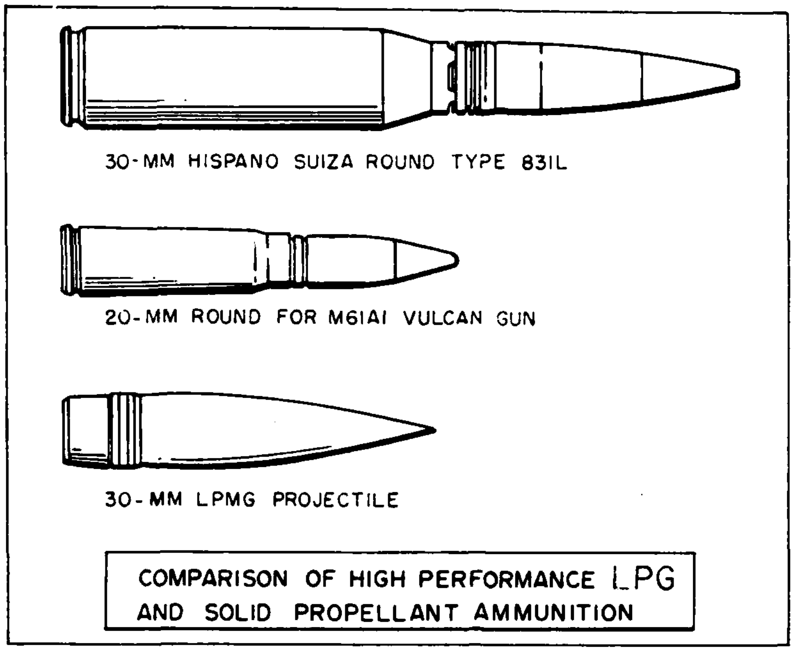


FIG. 41.

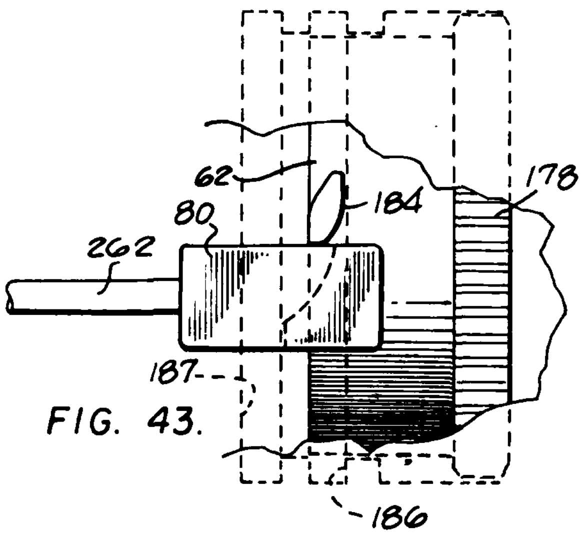


FIG. 43.

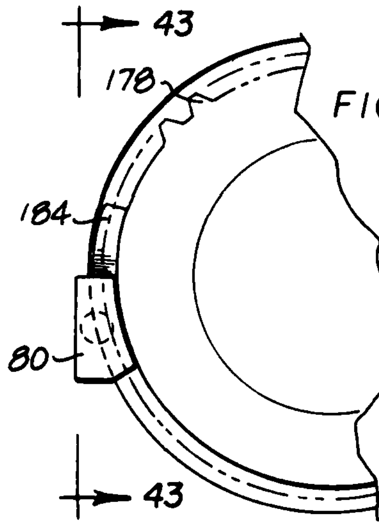


FIG. 42.

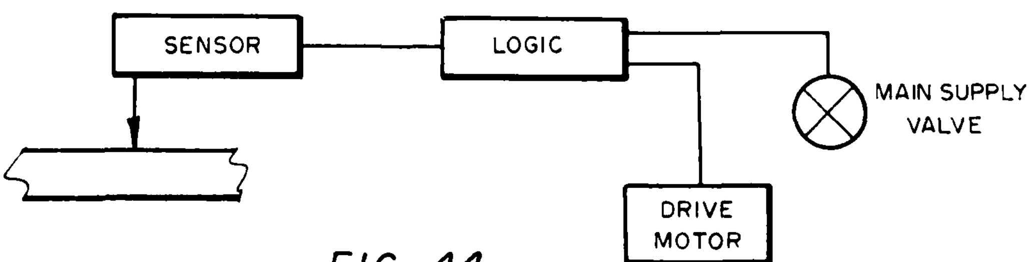


FIG. 44.

LIQUID PROPELLANT MODULAR GUN INCORPORATING DUAL CAM OPERATION AND INTERNAL WATER COOLING

BACKGROUND OF THE INVENTION

This invention relates to a liquid propellant gun of the kind in which liquid propellant is burned in a combustion chamber to fire a projectile from the gun. It relates particularly to a cam operated, externally driven, liquid propellant gun having a slim profile so that a plurality of single barrel gun modules can be conveniently clustered in a variety of configurations. The present invention also relates particularly to an internal water cooling arrangement which injects a small quantity of water into the combustion chamber for cooling by internal vaporization after the firing of each round and which also serves to fill the combustion chamber with water and to purge propellant from the combustion chamber in the event of a misfire.

The present invention has particular utility for high performance, high rate of fire guns in the 20 to 35mm size. The present invention is not, however, limited to guns of this size.

The existing weapons used by the armed services use solid propellant cartridges. These existing weapons carry the solid propellant in cases, and the cases form a substantial part of the overall weight and overall size of the cartridge. This in itself imposes serious drawbacks and limitations on the installation and use of such weapons, because the projectile feed mechanism and related storage facilities must be large enough and strong enough to store and transport not only the projectile itself but also the related solid propellant and case.

Solid propellants have a further inherent disadvantage because of the fact that solid propellants characteristically develop a high peak temperature. In many gun installations it is necessary to fire long bursts in multiple engagements. Such projected firing schedules produce severe thermal loads on the gun and often cause barrel errosion with the existing solid propellant weapons.

Automatic guns used in antiaircraft roles are a good example of guns subjected to severe firing schedules. Long bursts are needed to achieve high cumulative kill probabilities. These gun systems must also engage multiple targets in rapid succession with little or no time between bursts for adequate cooling. A severe barrel cooling problem results which is a primary factor in limiting system effectiveness. The reduced accuracy associated with premature barrel errosion can effectively destroy gun capability during a single engagement. The alternative is to increase the number of available mounts to achieve an acceptable firing schedule. This results in additional weight, complexity, cost and maintenance problems, and is therefore an unacceptable solution.

The problem has long been recognized in high performance, gun installations such as the U.S. Navy 40mm Bofors automatic gun and the Oto Melara 76/62. In both cases a classic approach to barrel cooling has been taken, i.e. water jacketing of the exterior barrel surface. However, even with exterior water jacketing, the heat transfer rate may be too limited for some applications.

The problems of severe thermal loads and barrel erosion also occur in drilling by cannon excavation. In cannon excavation the firing rate is relatively low but the duty cycle is sustained for long periods of time, and this produces severe thermal loads on the barrel.

It is one important object of the present invention to provide a more effective means for barrel cooling. This object is achieved in the present invention by internal water cooling. The way in which the internal water cooling is incorporated in a liquid propellant gun of the present invention also permits the mechanism for injecting the water for cooling to be used as a water purge system for purging the combustion chamber of liquid propellant in the event of a misfire, and this system and mode of operation constitutes another, specific object of the present invention. The internal water cooling system will be reviewed in more detail below in the Summary of the Invention and in the Detailed Description of the Preferred Embodiments of the present invention. At this point the applicants would like to point out that, because the water does impinge directly on the heated gun bore surfaces in the present invention, high heat transfer rates are realized and the effectiveness of the internal water cooling permits significant increase in burst length and frequency in automatic guns. It also permits a significant increase in length of the duty cycle in such applications as drilling by cannon excavation.

There are a number of recognized technical objectives for high performance guns. In general, these include (1) increased velocity and rate of fire; (2) lower gun and ammunition weight; (3) improved interior and exterior ballistic performance; (4) decreased erosion, flash and smoke; (5) reduced recoil loads; (6) elimination of cases, links and sabots; (7) improved reliability and safety; and (8) versatility—application to a wide range or requirements.

In addition to these general improvements, the following characteristics are recognized as being factors lacking in the prior art and needed to enhance the applicability of future gun systems as compared to the prior art: (1) a gun of minimum cross section to assure maximum versatility of installation on shipboard, vehicle and aircraft mounts; (2) an envelope that will assure retrofit capability of single or multibarrel high performance 30 or 35mm liquid propellant guns in existing 20mm installations; (3) a mechanism design capable of employing high density, low drag projectiles currently in the inventory or in an advanced stage of development; (4) at the 30/35mm scale—utilization of existing projectile designs (with only minor modifications) to eliminate immediate requirements for development of new projectiles, and muzzle velocities in excess of 4000 ft. per second employing high sectional density projectiles to provide adequate standoff, short time of flight, and high projectile payload; (5) a gun mechanism construction adaptable to operation at higher muzzle velocities when adequate projectiles are available; (6) stationary barrel construction with rotating cam feed mechanism to provide significant reduction in gun drive power requirements and quicker acceleration to full firing rate; (7) simplified gun harmonization at all firing rates by elimination of tangential projectile velocity components associated with rotating barrel systems.

A further requirement which has been placed on gun development in guns of this size range is that the gun must be applicable across the board to sea, air and ground needs for the three services. These include (but are not limited to) small craft point defense, landing craft armament, retrofit of existing fixed wing aircraft and antiaircraft and antivehicle ground applications where rate of fire and configuration constraints vary widely. Some missions require single barrel guns with relatively low, adjustable rates of fire (0 to 1000 rpm).

Others involve multibarrel installations at intermediate rates of fire (2000 to 3000 rpm), and finally there are those which require very high rates of fire (4000 to 6000 rpm). It can be seen that this range of rate of fire indicates that automatic guns are needed from one to eight barrels.

Liquid propellant guns have a characteristic low peak temperature. Because a liquid propellant will ignite in the bulk mode, it can be ignited, as by an electrical spark device immersed in the liquid propellant, without the need to vaporize the propellant prior to ignition. Liquid propellants are high energy density liquids and can be burned in discrete pulses to product high combustion pressures. Pulsed burning of a liquid propellant can produce combustion pressures in the range of 10,000 to 80,000 psi and even higher. The magnitude of the average combustion pressure in such pulsed burning can be controlled by the amount of expansion permitted. Higher average combustion pressures can be produced by permitting less expansion.

The liquid propellant gun can produce a flatter combustion chamber pressure-time characteristic than a solid propellant gun. Hence, performance equivalent to a solid propellant gun can be obtained at lower pressure. High cyclic rates of fire are possible with a liquid propellant gun. Because the propellant is a liquid, the propellant can be easily pumped to the firing chamber from a storage area remote from the gun itself. This permits flexibility of installation. Because the cartridge feeding system of the liquid propellant gun carries only the projectile itself, the projectile feed system can be simplified and can be made considerably lighter in weight than for a conventional gun. Or, a considerably larger projectile size and weight can be used for higher performance without having to increase the size of the projectile feed mechanism. This is especially important in permitting larger bore liquid propellant guns to be incorporated in retrofit installations as replacements for existing smaller bore solid propellant guns.

Liquid propellant guns also permit slim profiles which provide desirable configuration versatility. Because the liquid propellant gun permits a low profile, clean exterior design, an individual liquid propellant gun module or a modular grouping of liquid propellant gun modules can be installed in locations that would not accomodate a conventional gun.

It is another important object of the present invention to incorporate the inherent advantages of a liquid propellant gun in a modular gun of the kind incorporating a drive cam and a control cam.

SUMMARY OF THE INVENTION

The liquid propellant gun of the present invention is a cam operated, externally driven gun constructed in modular form. It has a slim profile, and the operational features of the gun are arranged so that the gun can be readily incorporated in a variety of modular clusters, such as flat pack groupings and circular groupings.

The gun barrel is stationary and all combustion chamber pressure loads on the bolt are carried through the barrel rather than being carried through the receiver with the result that the receiver can be made quite light.

The gun incorporates two cams, a drive cam and a control cam.

The drive cam reciprocates the bolt back and forth between a rearward, projectile loading position and a forward, projectile firing position. The drive cam is a hollow cylindrical member having two spiral cam tracks formed on the inside of the drive cam. The first sprial cam track engages a cam follower on the bolt to drive the bolt forward, and the other spiral cam track engages the cam follower to drive the bolt rearward as the drive cam is rotated about the axis of reciprocation of the bolt.

The control cam is located at the front end of the drive cam, and the control cam is also an annular member which is rotated about the axis of the bolt. The control cam controls the injection of the liquid propellant into the combustion chamber and also controls the igniter for igniting the propellant.

The drive cam is rotated faster than the control cam and has dwell or rest areas at each end of the drive cam to provide the time intervals for the projectile loading at one end and the propellant injection and firing at the other end of the bolt's reciprocation.

The drive cam rotates the bolt in one direction at the end of its forward travel to lock the bolt to the barrel, and the control cam rotates the bolt in the opposite direction after firing to unlock the bolt from the barrel.

The axial sliding movement of the reciprocating bolt is guided by lugs on the bolt which interfit in slots in the barrel extension or receiver of the gun.

The cam follower of the bolt is mounted for a limited amount of radial movement with respect to the bolt to accomodate, by outward movement, the bolt rotation required to lock the bolt and, by inward movement, the required dwell at the forward end of the bolt travel. The barrel extension has a cam surface that coacts with the cam follower and a dwell area at the forward end of the drive cam to provide the required dwell in this part of the cycle of operation of the gun. The control cam unlocks the bolt and returns the cam follower to the rearward, spiral drive cam track at the proper time.

The drive cam and the control cam are driven in synchronism by interconnected gearing, and the drive cams of adjacent gun modules are interconnected by idler gears for transferring drive from one module to the next.

The gun of the present invention incorporates a water cooling arrangement in which the control cam causes a small amount of water to be injected into the combustion chamber after the firing of each round. The injected water is vaporized and converted to steam as it contacts the hot combustion chamber structure, and this produces a highly effective cooling of the combustion chamber structure.

The water cooling valving is interconnected with the valving for the propellant injection in a manner such that the combustion chamber can be completely filled with water to purge the combustion chamber of propellant in the event of a misfire.

The gun incorporates misfire detection means which coact with the control cam to completely disengage the control cam from the drive so that operation of the gun module is stopped in the event of a misfire.

Liquid propellant gun apparatus and methods which incorporate the structure and techniques described above and which are effective to function as described above constitute specific objects of this invention.

Other objects, advantages and features of our invention will become apparent from the following detailed description of preferred embodiments taken with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is an isometric view of a liquid propellant gun module constructed in accordance with one embodiment of the present invention;

FIG. 2 is an isometric view showing three of the gun modules of FIG. 1 grouped in a flat pack cluster;

FIG. 3 is an isometric view showing three of the gun modules of FIG. 1 grouped in a circular cluster;

FIG. 4 is a side elevation view of the gun module shown in FIG. 1;

FIG. 5 is an enlarged top plan view of the gun module taken along the line and in the direction indicated by the arrows 5—5 in FIG. 4. In FIG. 5 some parts are partly broken away to show details of construction and FIG. 5a is a continuation of the left hand end of FIG. 5;

FIG. 6 is a side elevation view in cross section taken generally along the line and in the direction taken by arrows 6—6 in FIG. 5 and FIG. 5a. FIG. 6a is a continuation of the left hand end of FIG. 6. The cam follower 64 is shown rotated 30° in FIG. 6 for better illustrating its operation. See FIG. 13 for the true position of this cam follower;

FIGS. 7-14 are end elevation views in cross section taken along the lines and in the directions indicated by the correspondingly numbered arrows in FIG. 6;

FIG. 15 is an end elevation view taken along the line and in the direction indicated by the arrows 15—15 in FIG. 4;

FIGS. 16-21 are isometric views showing the disposition of certain parts of the gun in the various phases of operation indicated by the legends in these figures;

FIG. 22 is a fragmentary, enlarged view of the part of the structure shown encircled by the arrows 22—22 in FIG. 6. In FIG. 22 as in FIG. 6, the cam follower is shown rotated 30° from its actual position illustrated in FIG. 13;

FIG. 23 is a fragmentary, enlarged end elevation view taken along the line and in the direction indicated by the arrows 23—23 in FIG. 22, but with the cam follower at the actual inclination illustrated in FIG. 13;

FIG. 24 is a fragmentary, enlarged end elevation view taken along the line and in the direction indicated by the arrows 24—24 in FIG. 22 showing the cam follower 64 in the unlocked position in phantom outline and in a locked position in bold outline;

FIG. 25 is a fragmentary, enlarged bottom plan view taken along the line and in the direction indicated by the arrows 25-25 in FIG. 23;

FIG. 26 is a fragmentary enlarged side elevation view taken along the line and in the direction indicated by the arrows 26—26 in FIG. 5. FIG. 26 shows the positions of the water injection and the propellant injection control valves during firing of the gun;

FIG. 27 is a fragmentary enlarged side elevation view like FIG. 26 but showing the positions of the water injection and propellant injection control valves during propellant loading;

FIG. 28 is a view like FIGS. 26 and 27 but showing the positions of the water injection and propellant injection control valves during either the combustion chamber cooling or the emergency purge operations;

FIG. 29 is a fragmentary, enlarged view of the front face of the control cam and is taken generally along the line and in the direction indicated by the arrows 29-29 in FIG. 19. FIG. 29 shows the recess in the control cam for the control of the propellant injection, the projection on the control cam for the water injection and a projection on the control cam for controlling the operation of the igniter;

FIG. 30 is a fragmentary enlarged plan view taken generally along the line and in the direction indicated by the arrows 30—30 in FIG. 29;

FIG. 31 is a top plan view showing five gun modules assembled in a flat pack cluster together with a drive motor for the gun modules and the projectile feed system;

FIG. 32 is an end elevation view taken generally along the line and in the direction indicated by the arrows 32—32 in FIG. 31. FIG. 32 shows the feeding of specific projectiles in the endless conveyor belt to related gun modules;

FIG. 33 is an end elevation view like FIG. 32 but showing the projectile feed system for three gun modules assembled in a circular cluster;

FIGS. 34-39 illustrate different cluster configurations for the modular gun of the present invention and illustrate how projectile feed sytems are associated with these different cluster configurations;

FIG. 40 is a plan view showing a size comparison for high performance 30mm liquid and solid propellant rounds of ammunition and also illustrates the relative feed chute sizes required;

FIG. 41 is a top plan view showing a size comparison of a 30mm liquid propellant projectile, a conventional solid propellant 20mm round for an M61 Vulcan gun and a conventional solid propellant round for a 30mm Hispan Suiza round type 831L. FIG. 41 illustrates how a 30mm liquid propellant round is approximately the same overall length as a conventional solid propellant 20mm round and how it is therefore capable of being substituted in conventional projectile feed systems for smaller 20mm solid propellant rounds with a minimum of retrofit modifications;

FIG. 42 is a fragmentary and elevation view showing details of the misfire switch and control cam shifting lug;

FIG. 43 is a fragmentary side elevation view taken along the line and in the direction indicated by the arrows 43—43 in FIG. 42;

FIG. 44 is a schematic view of a pressure sensing interlock system for stopping operation of a gun module in the event of a drop in propellant feed pressure.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

A liquid propellant gun module constructed in accordance with one embodiment of the present invention is indicated generally by the reference numeral 50 in FIGS. 1, 4, 5, 6 and 16 through 21.

The gun module 50 includes a barrel 52, a combustion chamber 54, a bolt 56, a barrel extension or receiver 58, a drive cam 60, a control cam 62, a cam follower 64, a projectile loading mechanism 66 for loading projectiles from a projectile feeding mechanism 68, a drive mechanism 70, propellant injection means 72, water coolant and purge means 73, a bolt sear 74, an igniter 76, misfire detection means 78 and a misfire switch 80, all as indicated generally by these reference numerals in FIGS. 5 and 6 and in other Figures of the drawings.

The gun module 50 illustrated in the drawings uses a liquid monopropellant (i.e. a liquid propellant that contains both a fuel and an oxidizer) in the combustion chamber 54 for firing a projectile 84. It should be noted, however, that many of the features of the present invention are not limited to a modular gun or to a gun using

a monopropellant, as will become more apparent from the description to follow.

The bolt **56** is reciprocable back and forth between a rearward, projectile loading position (see FIG. **16**) and a forward, projectile firing position (see FIGS. **18, 19** and **20**).

The bolt is guided in this reciprocating movement by lugs **86** (see FIG. **17** and FIG. **9**) which slide within guide slots **88** (see FIGS. **19** and **11**) in the barrel extension **58** and guide slots **90** (see FIG. **18** and FIG. **10**) extending through locking lugs **92** at the rear end of the barrel **52**.

The igniter **76** is located in the front face of the bolt **56** and comprises an electrode **91** (see FIG. **6** and FIG. **11**) which is energized when a cam follower (not illustrated) is displaced by a projection **94** on a forward control face **96** of the control cam **62** (see FIGS. **29** and **30**). Energization of the electrode **91** produces electrical energy which ignites the liquid propellant in the combustion chamber **54** to fire the projectile **84** out of the barrel **52**. Ignition can also be accomplished by compression ignition or by injecting a chemical into the propellant.

The forward face of the bolt **56** has a seal **96** as best illustrated in FIG. **6**.

The rear end of the bolt **56** has a bolt extension **100** which coacts with the projectile loading mechanism **68** to snap a projectile out of a spring clip carrier in the projectile feed mechanism **66** (in a way to be described in more detail below) when the bolt is moved to the rearward, projectile loading position.

The bolt extension **100** also has a detent **102** which is engaged by the pawl of the sear **74** to hold the bolt in the rearward position when the gun trigger is off and a sear solenoid **104** is deenergized.

A sear actuating rod **106** is connected to the rear solonoid **104** and has a slot **108** (see FIG. **6**). A pin **110** rides in the slot **108** at the lower end of the pivot arm and is connected at the lower end of the pivot arm **112** of the sear **74**. The arm **112** pivots about a sear pivot **114** which straddles the spring cavity. As illustrated in FIG. **6**, a spring **116** normally biases the sear pawl **74** toward a bolt retaining position, but energization of the sear solonoid **104** rotates the pawl **74** downward to the bolt releasing position (best illustrated in FIG. **21**).

The end face **118** of the bolt extension **100** is engageable with a face **120** of a spring backed part **124** which actuates the projectile loading mechanism **66**. The back face of the part **124** provides a spring seat for one end of a bolt return spring **126**. (See FIG. **6**). The other end of the bolt return spring **126** is seated against an inner face of a rear cover **128**.

The part **124** has an upwardly projecting flange **129** which is engageable with an actuator level **130** of the projectile loading mechanism **66**. The upper end of the actuator level **130** is connected to a push rod **132** by a pin joint connection **134**, and a spring **136** maintains the lower end of the actuator lever **130** in engagement with the upwardly extending flange **129**.

The front end of the push rod **132** is connected to a bellcrank loading lever **138** by a pin joint connection **140**. The downwardly extending arm of the bellcrank projectile loading lever **138** is pivotally connected to the barrel extension **58** by a loading lever pivot **141**.

The forwardly extending arm of the projectile loading lever **138** has a lower end **142** which is positioned over an upper recess **144** in a spring clip carrier **146** for a projectile **84**. This projectile is aligned with the upper end of a projectile receiving passageway **148** in the barrel extension **58** (see FIGS. **10** and **11**).

Engagement of the bolt extension **100** with the rod **120** moves the lower end of the actuator lever **130** about the pivot provided by the connection to the spring **136** to shift the rod **132** forward. This pivots the bellcrank **138** about the pivot **141** and snaps a projectile **84** out of the spring clip carrier **146** of the endless conveyor belt **149** (see FIG. **32**) of the projectile feed mechanism **68**.

The projectile drops into the passageway **148** and into the bore in the barrel extension in front of the bolt **56**. Forward movement of the bolt **56** then pushes the projectile up into the barrel **54**, and the projectile **84** is then pumped forward (to the position illustrated in FIG. **6**) against the forcing cone **150** by the liquid propellant injected into the combustion chamber. This will be described in greater detail below.

The barrel **52** is connected to the barrel extension **58** by cap screws **152** (see FIG. **6**).

A cam cover **154** is connected to the barrel extension **58** by cap screws **156** as also shown in FIG. **6**.

The drive cam **60** has two internal, spiral shaped, cam paths **160** and **162** which are engageable with the cam follower **64** for reciprocating the bolt **56** forward and backward during operation of the gun. The spiral cam track **160** drives the bolt **56** forward, and the spiral cam track **162** drives the bolt **56** rearward.

The drive cam **60** is axially elongated so that the cam angles are not too high, and the drive cam is rotated faster than the control cam **62**.

As best shown in FIGS. **1–3** and **31**, the drive system **70** includes a drive motor **164**. The drive motor **164** rotates an idler gear **166**, and the idler gear **166** is engaged with a gear **168** formed on the outer diameter of the drive cam **60** at the rear end of the drive cam **60**.

FIG. **15** illustrates how this same idler gear **166** is used to transfer the drive from one module to an adjacent module in a cluster arrangement.

The drive to the control cam **62** is provided by a jack shaft take off gear **170**, a jack shaft **172**, a jack shaft pinion gear **174**, an idler gear **176** and a gear **178** formed on the outer diameter of the control cam **62** (as best illustrated in FIGS. **6** and **16** through **21**). The control cam **62** is therefore rotated in a direction opposite from that of the drive cam **60**, as indicated by the arrows in FIG. **17**.

In a particular embodiment of the present invention the gear ratios are such that the drive cam **60** is rotated four times as fast as the control cam **62**.

The drive cam **60** is mounted for rotation on the barrel extension **58** by bearings **180** at the rear end of the drive cam and **181** at the forward end of the drive cam (see FIG. **6**).

The control cam **62** is mounted for rotation on a surface **182** of the barrel extension **58** and is normally retained in a fixed axial position with respect to the barrel extension **58** by two radially projecting cam lobes **184** on the outer periphery of the control cam **62** (see FIG. **12**). The lobes **184** travel in an annular groove **186** in the barrel extension **58**. In normal operation of the gun the lobes **184** travel in the groove **186** and the control cam **62** is maintained in the fixed axial position illustrated in FIG. **6** with the gear **178** engaged with the gear **176**. However, the barrel extension **58** has a relieved space **188** in front of the control cam which permits the control cam to be shifted axially forward and disengaged from the drive connection with the idler gear **176** in the event of a misfire. In this condition of

operation as illustrated in FIG. 43 and as will be described in more detail below, the misfire switch 80 engages one of the cam lobes 184 to move the control cam 62 forward. The cam lobe that engages the misfire switch is diverted into a dead end side track 187, and the other lobe 184 enters a relieved area.

As best illustrated in FIGS. 6 and 13, the cam follower 64 is a cylindrical element at the outer end of a rod 190. The rod 190 is mounted for axial movement in a radially extending bore 192 at the back end of the bolt 56. The underside of the bolt 56 has a recessed groove 194, and a leaf spring 196 is mounted in the groove 194 so as to engage the lower end of the rod 190. The spring 196 biases the cam follower radially outwardly and into engagement with associated surfaces on the drive cam 60 and, during part of the time that the bolt 56 is in its forward projectile firing position, with associated large diameter surface 206 and smaller diameter surface 208 on the barrel extension 58. See FIG. 24. This will be described in more detail below.

During forward driving movement of the bolt 56, the outer surface of the cam follower 64 is engaged with a surface 199 of the forward driving cam track 160. See FIGS. 6, 17 and 22. During rearward driving of the bolt 56, the outer surface of the cam follower 64 is engaged with a surface 197 of the spiral cam track 162.

The drive cam 60 has dwell or rest areas at the front and rear ends of the drive cam. The dwell areas provide turnarounds at each end of the bi-directional drive cam.

The rear dwell area includes a surface 201 which is bounded by a rear, radially inwardly extending flange 203 and a forward, inwardly extending flange 205. See FIG. 6. This dwell area at the rear of the drive cam holds the bolt 56 in a retracted position from the time that the cam follower 64 leaves the return cam track 162 until the drive cam is rotated to a position in which an opening in the forward flange 205 permits the bolt return spring 126 and part 124 to shove the cam follower 64 into the forward drive cam track 160.

In a particular embodiment of the present invention (having the 4 to 1 ratio of drive cam revolutions to control cam revolutions for each cycle of operation as noted above), the cam follower 64 rests at the rear dwell area of turnaround for 0.6 turn of the drive cam 60. The forward drive spiral 160 moves the cam follower forward for 0.8 turn of the drive cam 60. The cam follower moves rearward for 0.8 turn of the drive cam and rests at a forward dwell area for approximately 1.8 turns of the drive cam 60.

When the bolt 56 reaches the forward end of its travel, it must be rotated 45° (as illustrated in FIG. 13) to lock the lugs 86 on the bolt in front of the lugs 92 of the barrel 52 (see FIG. 18).

The construction of the forward end of the drive cam 60 and related structure of the barrel extension 58 and back face of the control cam 62 are best illustrated in the enlarged fragmentary view of FIG. 22.

As best illustrated in FIG. 22, when the cam follower 64 leaves the forward end of the forward drive cam track 160, the back side of the cam follower 64 is positioned in a forward dwell area 198 so that continued rotation of the drive cam 60 cannot produce any continued forward movement of the bolt 56.

The drive cam 60 does, however, have a slot 200 (see FIGS. 22 and 23) located at the forward, outlet end of the forward cam track 160 so that the spring 196 (see FIG. 6) shoves the rear half of the cam follower 64 outward and into this slot 200 as soon as the forward reciprocation of the bolt has been completed. The rotation of the drive cam 60 in the clockwise direction indicated by the arrow in FIG. 17 then rotates the cam follower and bolt 45° to the locking position illustrated in FIG. 18.

At the same time that the back half of the cam follower 64 moves into the slot 200, the front half of the cam follower 64 engages the large diameter surface 206 (see FIG. 24) of the barrel extension 55. This surface 206 has a ramp 206*a* which decreases in diameter, as the bolt is rotated 45° to the locked position, until the diameter is the same as that of the surface 208. This ramp 206*a* pushes the cam follower 64 downward from the outwardly extended position shown in phantom outline in FIG. 24 to the retracted position shown in solid outline in FIG. 24.

The surface 208 thereafter engages the top of the front half of the cam follower 64 to retain the cam follower 64 in the retracted position and within the groove 198 of the drive cam 60 until the firing of the projectile from the combustion chamber 54 has been completed and the bolt 56 is ready to be rotated back 45° to an unlocked position and then retracted to the projectile loading position by engagement of the cam follower 64 within the rear drive cam track 162.

While the cam follower 64 is retained in the retracted position illustrated in FIG. 24 by the stationary engagement of the cam follower 64 with the surface 208 at the end of the ramp 206, the drive cam 60 is of course continuing to rotate with respect to the cam follower 64 with the back half of the cam follower 64 engaged in the relieved area of the recessed face 198. At the same time the rear face 210 of the control cam 62 is rotating counter clockwise with respect to the cam follower 64, as illustrated by the arrows in FIGS. 18 and 19.

The rear face 210 of the control cam has a bolt unlocking and return wedge 212 projecting outwardly from the rear face 210. As this wedge rotates into engagement with the cam follower 64, it first of all rotates the cam follower and bolt 45° counter clockwise (as viewed in FIG. 20) to unlock the bolt by aligning the lugs 86 with the slots 90. Continued rotation of the control cam 62 then moves the cam follower 64 axially to the rear and into the front inlet end of the rear drive cam track 162, as this end of the cam track 162 opens to the front dwell area 198. Continued rotation of the drive cam 60 then reciprocates the bolt 56 to a rearward, projectile loading bolt position.

The gun 50 as illustrated in the drawings uses a liquid monopropellant, i.e. a liquid propellant having both a fuel and an oxidizer. Mixtures of hydrazine, hydrazine nitrate and water are examples of monopropellants that may be used. However, propellants developed for torpedo application have physical, performance, handling and safety characteristics that are well suited for use in the present invention. This is understood since torpedo propellants must be compatible with the long duration, closed environment of a submarine where adverse characteristics from the standpoint of toxicity, handling or safety are completely intolerable. The liquid propellant is stored, either adjacent to the gun 50 or remotely, and is conducted to the propellant injection means 72 by a flex conduit 216 as shown in FIGS. 18 and 19. The propellant supply pressure is supplied either by pump 217 (See FIG. 18.) or by an accumulator subsystem (not illustrated). The accumulator is preferable from the standpoint of being effective in reducing pump volume requirements while meeting the peak flow rates neces-

sary for burst fire. The propellant supply system includes a pressure sensing interlock system (see FIG. 44) which senses the propellant pressure by means of a sensor and stops operation of the complete group (row or cluster) of gun modules by closing a main propellant supply valve and stopping operation of the drive motor when the supply pressure drops below an established level. This prevents incomplete propellant filling.

The porting and valving arrangement for controlling the injection of liquid propellant into the combustion chamber **54** is best shown in FIGS. **5**, **8**, **18** and **26–28** of the drawings.

As best illustrated in FIG. **26**, the sidewall of the barrel **52** has an axially extending bore **218** at one side of the combustion chamber **54**, and the propellant conduit **216** is connected with a port **200** at one end of the bore. A port **222** connects the other end of the bore to drain.

A spool valve **224** is mounted for axial movement within the bore **218**, and the control of the position of the spool valve **224** is provided by a valve control rod **226** which is connected to the valve spool **224** at one end. The other end of the rod **226** is engaged with the front face **96** (see FIG. **29**) of the control cam **62** and acts as a cam follower.

A port **228** connects the axial bore **218** with the combustion chamber **54**.

The valve spool **224** has annular seals **230** at each end of the spool and the rod **226** is sealed by a seal **232** as illustrated in FIG. **26**.

The cam face **96** of the control cam **62** is formed with a recessed ramp **234** which controls the duration of the time period for injection of the liquid propellant through the ports **220** and **228**. The control rod **226** is biased (by the propellant supply pressure) to the right (as viewed in FIG. **26**) so that the cam follower end of the rod **226** is maintained in engagement with the face **96** of the rotating control cam **62**.

In the firing position, the valve spool **224** is positioned by the control rod **226** to block off the port **228** (as illustrated in FIG. **26**).

FIG. **27** illustrates the position of the valve spool **226** with respect to the port **228** when the recess **234** of the control cam **62** has been rotated to a position in which the control rod **226** first drops down into the recess **234**. The valve spool **224** is shifted to the right in the bore **226** to open the port **228** for communication with the port **220**, and the liquid propellant flows into the combustion chamber under the pressure of the propellant supply system. The pressure of the inflowing propellant pumps the projectile **84** forward to the position illustrated in FIG. **6a**. The inclined ramp in the recess **234** pushes the control rod **226** leftward and back to the position illustrated in FIG. **26** as the cam follower end of the control rod **226** returns to the plane of the front face **96** of the control cam **62**. The amount of liquid propellant injected is therefore determined by the pressure of the propellant supply system and the length and angular inclination of the recess **234**.

As illustrated in FIG. **29**, the front face **96** of the control cam **62** has a projection **94** which is engaged by a spring biased cam follower. The electrode **92** is energized as the igniter cam follower is actuated by the projection **94** following the filling of the combustion chamber **54** with the liquid propellant.

A very important feature of the present invention is the internal water cooling provided by the coolant injection means **73**.

The coolant injection means **73** inject a small quantity of water directly into the firing chamber **54** between rounds. Since water impinges directly on the heated gun bore surfaces, high heat transfer rates are realized. The effectiveness of the internal water cooling permits a significant increase in burst length and frequency in the case of an automatic gun fired at high cyclic rates and permits a significant increase in the length of the duty cycle of guns used at lower cyclic rates such as in common excavation.

In a specific embodiment of the present invention water is used as the cooling liquid because it has a high heat of vaporization and is readily available. Other liquid coolants can of course be used, but the description to follow will be directed specifically toward the use of water as the coolant liquid.

One embodiment of the valve structure for accomplishing the internal water cooling is illustrated in FIGS. **5** and **26–28**. As illustrated in these drawings, the wall of the gun barrel **52** has an axially extending bore **236**. A valve spool **238** is mounted for reciprocation within the bore, and the valve spool has seals **240** at each end.

A water inlet port **242** is connected to one end of the bore **236** and a hose is attached to this port **242** to connect the port to a pressurized water supply system.

A port **244** connects the bore **236** to the combustion chamber **54**.

The valve spool **238** is connected directly to the valve spool **224** through an extension of the rod **226** so that the water coolant valve spool **238** moves in unison with the propellant injection valve spool **224**.

Seals **246** and **248** seal off the part of the rod **226** extending between the bores **236** and **218**.

In the firing position of the valve spools (as illustrated in FIG. **26**) the valve spool **236** blocks flow of water *into* the port **224** and flow of combustion gases out of the port **244**.

Similarly, the water injection valve spool **238** is positioned in the propellant loading position illustrated in FIG. **27** to block flow through the port **244**.

However, immediately after firing, the control cam **62** rotates to a position in which a projection **250** shifts the control rod **226** leftward (as viewed in FIG. **28**) by an amount sufficient to open the port **244**. This projection **250** permits a short time period for the injection of coolant water into the combustion chamber (through the passageway provided by the ports **242**, the bore **236** and the port **244**) before the cam follower end of the control rod **226** moves down off the projection **250** and back onto the plane of the face **96**. This small amount of water is vaporized by the hot wall structure of the combustion chamber and turned to steam. During this water injection period, the port **228** may be maintained closed by the land **224** or, depending on the size of the projection **250**, the port **228** may also be opened for venting of gas and steam from the combustion chamber (through the port **228** and the bore **218** and the vent port **222**).

Thus, immediately after firing each round, the coolant injection means **73** are opened and a metered quantity of water is injected directly on the forward portion of the combustion chamber **54**. The water spray is directed toward the combustion chamber surfaces of the gun. The quantity of water is metered to insure that virtually all of it is converted to steam.

The next projectile **84**, in the process of being loaded and pumped forward in the chamber, pushes any steam and water remaining in the chamber ahead of the pro-

jectile into the barrel. After firing, the residuals are forced out of the barrel by the projectile as it traverses the bore.

If the distribution of the water vapor in the bore is assumed to be the same as the normal products of combustion of a liquid propellant, the weight of gas (vapor) being pushed out by the projectile is slightly less than that for a conventional solid propellant round. This results from the somewhat lower molecular weight of liquid propellant combustion products and that of the water vapor.

The internal water cooling is optimized to inject no more water than is vaporized. Hence, there is no penalty for acceleration inert mass. The water injected is controlled by the dwell of the surface **250** of the control cam **62**.

Heating and cooling of a gun barrel bore surface is highly transient. The analysis of the instantaneous heat transfer process is complex and methods for accurately determining the heat transfer coefficient controlling the process are not well established. However, the following example, based on average conditions, does illustrated the effectiveness of the internal water cooling.

Considering a 35mm 4,000 ft/sec muzzle velocity liquid propellant gun, the significant characteristics are:

Projectile Weight	1.2 lb.
Muzzle Velocity	4,000 ft/sec.
Propellant Charge	1 lb.
Projectile Muzzle Kinetic Energy	298,000 ft.-lb.
Firing Rate	750 rounds per minute

Estimates of barrel heating per round are calculated using the criteria established by Corner[1] where the heat loss Q is:

$$Q = X(\tfrac{1}{2} W_1 V^2)$$

W_1 = "Effective" Mass of the projectile
V = Muzzle velocity
$X \approx 0.3$ (maximum value)

[1] "Theory of the Interior Ballistics of Guns". J. Corner. pg. 141. John Wiley & Son.

For the characteristics of the 35mm 4,000 ft/sec LPG, Q = 125,00 ft.-lb. (or 161 B.t.u.).

Gun barrel cooling is accomplished by direct water injection on the interior heated surfaces. Assuming initial water temperature to be 70° F, the heat absorption capability of the injected water (including specific heat and heat of vaporization) is approximately 1,110 B.t.u./lb. The quantity of water required for complete cooling after each round is then =

$$\frac{161\ \text{B.t.u./round}}{1110\ \text{B.t.u/lb.}H_2O} \text{ or } .146\ \frac{\text{lb.}H_2O}{\text{round}}$$

In a rapid fire automatic weapon, the time available for cooling between rounds is limited by heat transfer rate. At a firing rate of 750 rounds per minute, the cycle time per round is 80 milliseconds.

The heat transfer rate can be estimated from the following:

$$q = hA\Delta T$$

q = rate of heat transfer B.t.u./hr.
h = heat transfer coefficient B.t.u./hr. of ft²
A = area ft²
ΔT = temperature difference ° F.

For estimating the heat transfer rate, the following assumptions are made:

a. ΔT

Bore surface temperature rises of 1,200° - 1,400° F in one millisecond have been measured in liquid propellant guns at the origin of rifling. Since rapid injection of cooling water immediately after firing is involved in the present method, large average temperature differences will exist during the cooling process. Here a conservative ΔT of 500° F is assumed.

b. Area

The chamber bore surface area is 0.375 ft². It is assumed that the injected cooling water is effectively sprayed over an area at least equivalent to this, therefore, the effective area is assumed to be 0.375 ft².

c. Heat transfer Coefficient

Water sprayed against hot surfaces boils violently and is rapidly vaporized. Boiling heat transfer coefficients are quite high. Coefficients of ~300,000 B.t.u./hr. ft²° F are common. Here, the heat transfer coefficient conservatively is assumed to be 250,000 B.t.u./hr.ft²° F.

Based on these considerations, the rate of heat transfer is estimated to be:

$$q = (250{,}000\ \frac{\text{B.t.u.}}{\text{hr. ft}^{2\circ}\text{ F}})(.365\ \text{ft}^2)(500^\circ\ \text{F}) = 4.7.10^7\ \frac{\text{B.t.u.}}{\text{hr.}}$$

$$\text{or } 1.3 \times 10^4\ \frac{\text{B.t.u.}}{\text{sec}}$$

Since complete cooling per round requires removal of 161 B.t.u. the required cooling time is:

$$t = \frac{161\ \text{B.t.u.}}{1.3.10^4\ \frac{\text{B.t.u.}}{\text{sec}}} = 12.4\ \text{milliseconds}$$

With a total cycle time per round of 80 milliseconds there is ample cooling time available.

The above example is idealized in that perfect distribution of the cooling water over the heated surfaces is assured. While complete cooling is not usually attained in practice, a substantial portion of the heat imparted to the gun is removed. This has a major impact on firing schedule and gun system effectiveness.

FIG. **28** illustrates the disposition of the valve spools **238** and **224** in the event of a misfire, when it is desired to purge the combustion chamber **54** of all liquid propellant within the combustion chamber. In this event, the entire control cam **62** is shifted axially forward by the misfire detection switch **80**, and this shoves the control rod **226** leftward to the position illustrated in FIG. **28** where the valve spools **238** and **224** are held in the positions illustrated. The coolant water flows continuously into the combustion chamber through the coolant inlet port **244**, fills the combustion chamber **54** completely with water, and purges out all of the liquid propellant through the port **228** and the vent **222**.

A timing device, not illustrated, shuts off the flow of water through the hose **241** (see FIG. **7**) after a period of time sufficient to insure complete purging of the combustion chamber.

As described above in this specification, the misfire switch **80** is controlled by the misfire detection means **78** (see FIG. **5**).

The misfire detection means **78** include a gas piston **252** mounted for reciprocation within a cylinder **254** and spring biased by a spring **256** rightward (as viewed in FIG. **5**) to the position illustrated in FIG. **5** where a flange **258** engages a snapring stop **260**.

A connecting rod **262** connects the gas piston **252** to the misfire switch **80** so that the misfire switch **80** is normally spring biased to the position illustrated in FIG. **5** in which the misfire switch **80** is axially aligned with the lobes **184** on the control cam **62**.

A port **264** connects the bore of the barrel **52** with the interior of the cylinder **254** at the back face of the gas piston **252**.

A vent port **266** is located in the sidewall of the cylinder to vent the interior of the cylinder **254** to atmosphere.

As a projectile is fired from the gun, the pressurized gases behind the projectile flow through the pore **264** to momentarily move the gas piston **252** forward (leftward as viewed in FIG. **5**) within the cylinder **254**. This pulls the misfire switch **80** forward and out of alignment with the lobe **184** on the control cam long enough to let this lobe rotate past the misfire switch without engaging the misfire switch **80**.

However, if there is a misfire, the gas piston **252** remains stationary and the misfire switch **80** engages the cam lobe **184** to divert the cam lobe into a dead side track **187** (see FIG. **43** and FIG. **6**) while the other cam lobe **184** enters a relieved area. This moves the control cam **62** axially forward in the recess **188** (see FIG. **6**) to disengage the gear **178** from the idler gear **176**, and the rotation of the control cam **62** is stopped.

The timing of this action leaves the bolt **56** in a locked position with the breach closed.

In addition, as pointed out above, forward motion of the control cam **62** pushes the propellant fill valve **224** forward, exposing the combustion chamber fill port **228** to the port **222** at the rear of the bore **218** to permit purging of the liquid propellant from the combustion chamber **54**. At the same time the water inlet valve **238** is moved forward to open the water injection port **244**, and water is purged through the combustion chamber **54** to prevent cook off and to make the round inert.

The control cam disengagement disables that particular gun module but it does not disable the drive cam power train. Therefore, other modules in the banked row or cluster continue to operate and fire. Operation in this limited condition can continue until servicing. Projectiles intended for loading but passing over the disabled module are ejected at the end of the feed system transfer region.

If a projectile is missing at the feed system conveyor, a mechanical interlock system leaves a retainer in the path of the propellant fill valve **224** to prevent the valve from opening. As the module continues in a cycle of operation, a pseudo misfire occurs, and the module is disabled as described above.

Since complete propellant filling depends on fluid pressure in the propellant supply system with the monopropellant injection system described above, insufficient pressure of the propellant supply system could result in incomplete propellant filling. In the present invention when the supply pressure inadvertently drops below an established level, a pressure sensing interlock system (see FIG. **44**) stops operation of the complete group (row or cluster of modules).

The projectile feed system is best shown in FIG. **31**.

The projectile feed mechanism **68** employs a short endless conveyor **149** which is driven by a sprocket drive **270** from the drive motor **164**.

As best illustrated in FIG. **32**, the conveyor **140** mates with a transfer mechanism **272** to accept projectiles **84** from a conventional belt or linkless feed. The transfer mechanism **272** includes a shifting device which selects from separate projectile supplies to switch types of ammunition. The spring clip cradles **146** are the primary elements of the conveyor **149**. The tangs on the ends of the spring clip cradles slide in guide grooves in the conveyor frame. The cradles are coupled to form an endless, flexible chain.

Two configurations of the conveyor **149** are illustrated in FIGS. **31-32** and in FIG. **33**. In FIGS. **31** and **32** a flat conveyor passing over a banked row of modules is illustrated and in FIG. **33** a circular conveyor wrapping around a cluster of three modules is illustrated.

The flat conveyor configuration shown in FIGS. **31** and **32** demonstrates the loading scheme of the present invention which depends on a unique sequencing arrangement. In FIG. **32** a banked row of five modules served by the conveyor **149** are indicated by the reference numerals **1-5**. The projectiles **84** move along the conveyor from right to left and are numbered in groups of five, e.g. (5, 4, 3, 2, 1), (10, 9, 8, 7, 6), etc. The modules are also numbered (5, 4, 3, 2, 1) and are loaded in the sequence 1 through 5 and fire, of course, in the same sequence. Center-to-center spacing of the projectiles in the conveyor (1.75 in. for 30mm) is one-half the center—center spacing of the modules (3.5 in. for 30mm).

Assume projectile 1 is at the loading position for module 1. The loading lever on the module kicks the projectile out of the conveyor and into the module. The conveyor travels 1.75 inches between loadings. Projectile **2** was 1.75 inches away from the loading position for module **2** at the start but has now arrived in position and is loaded. Projectile **3** is now 1.75 inches away from the module **3** and will arrive at the loading position on time. The loading progresses until projectile **5** is loaded in module **5**, this projectile having moved 7.0 inches while the other projectiles were loading. By the time projectile **5** has been loaded, projectiles **10**, **9**, **8**, **7** and **6** have moved into positions occupied by projectiles **5**, **4**, **3**, **2** and **1** at the start. The process continues in perfect time, with projectile **6** loading into module **1**, projectile **7** loading into module **2**, etc. This loading scheme applies to any number of modules.

The circular conveyor for a cluster of three modules, shown in FIG. **33**, uses the same loading scheme as described above. Since the conveyor is circular, the cradles can take the form of pockets in a wheel-like structure. A minimum of six cradles or pockets are needed to properly feed the cluster. Nine pockets are shown in FIG. **33** to reduce the rotational speed of the conveyor and the centrifugal force imposed on the projectiles, thus reducing the force that must be exerted by the projectile loading levers at the modules.

Other cluster configurations as illustrated in FIGS. **34-39** are readily arranged and serviced by the projectile loading mechanism **68** as described above.

The modular system of the present invention can accomodate recoil adapters similar to those on the M-61 gun to reduce recoil forces. A banked row or cluster or modules can be supported mutually at the breach end of the barrels by a bracket structure that receives a pair (or more) of recoil adapters. An additional bracket struc-

ture mutually supports the rear of the modules and engages a short fixed slide to accomodate recoil travel. The latter bracket includes a provision for boresighting.

The impact of caseless operation on gun design is best illustrated in FIG. 41 which compares a 30mm liquid propellant modular gun projectile with a conventional 20mm round for the M-61 gun. Due to the similarity in length and diameter between the liquid propellant projectile and the solid propellant round, it is feasible to directly substitute the 30mm projectile for the existing 20mm cartridge. Some modifications are, of course, required due to slight differences in configuration but the overall volume is substantially the same.

FIG. 40 compares the diameter of a liquid propellant modular gun projectile in a 30mm size with the cartridge and projectile size for a conventional 30mm solid propellant round. This figure graphically illustrates the space and weight savings which can be achieved for the projectile feed systems in the 30mm gun size with the liquid propellant modular gun of the present invention.

While we have illustrated and described the preferred embodiments of our invention, it is to be understood that these are capable of variation and modification, and we therefore do not wish to be limited to the precise details set forth, but desire to avail ourselves of such changes and alterations as fall within the purview of the following claims.

We claim:

1. A gun of the kind in which liquid propellant is burned in a combustion chamber to fire a projectile from the gun and comprising,

- a gun barrel,
- a combustion chamber,
- a bolt mounted for axial movement between a rearward, projectile loading position and a forward, projectile firing position,
- liquid propellant injection means for injecting a liquid propellant into the combustion chamber,
- igniter means for igniting the liquid propellant in the combustion chamber,
- drive cam means for moving the bolt back and forth between the rearward and forward positions,
- drive means for driving the drive cam means, and
- control means for controlling the liquid propellant injection means and igniter means in coordination with the drive of the drive cam means.

2. The invention defined in claim 1 inclyding a receiver, a projectile loading passageway in the receiver, a projectile feed system including a spring clip for each projectile, and projectile loading means including a projectile loading lever movable to snap a projectile out of its spring clip and into the projectile loading track in the receiver in response to reciprocation of the bolt to its rearward projectile loading position.

3. The invention defined in claim 2 wherein the projectile loading lever includes a bell-crank member and the projectile loading means include an actuator lever engageable with the bolt and a push rod operatively connected to the bellcrank member at one end and to the actuator lever at the opposite end.

4. The invention defined in claim 2 wherein the projectile feed system includes an endless conveyor made up of said spring clips.

5. The invention defined in claim 1 including liquid coolant injection means for injecting a liquid coolant into the combustion chamber to cool the combustion chamber structure after the firing of each round.

6. The invention defined in claim 5 wherein the liquid coolant injection means include valve means operatively associated with the control means for controlling the timing and amount of liquid coolant injected.

7. The invention defined in claim 5 wherein the liquid propellant injection means and the liquid coolant injection means are connected together for movement in unison by a common control rod.

8. The invention defined in claim 5 wherein the liquid propellant injection means inject a monopropellant into the combustion chamber.

9. The invention defined in claim 8 wherein the control means include an annular control cam member mounted for rotation about an axis concentric with the axis of reciprocation of the bolt and having a forward generally planar extending surface formed with a recessed ramp, the propellant injection means include a propellant fill port, a control valve for the fill port, a rod having one end connected to the fill valve and another end engaged with said forward face of the control cam member, and pressure means for supplying the liquid monopropellant through the propellant fill port during the time that the control rod is engaged with the recessed ramp on the control cam means.

10. The invention defined in claim 5 wherein said liquid coolant injection means including a coolant inlet port, a coolant control valve associated with the coolant inlet port and a control rod having one end connected to the coolant control valve and the other end engaged with the control means.

11. The invention defined in claim 10 wherein the control means include an annular cam member having a front surface engaged with the control rod and including a projection on said front surface for momentarily opening the coolant inlet valve.

12. The invention defined in claim 11 including misfire detection means for pulling the entire control cam member and coolant inlet valve forward to a position in which the coolant control valve remains open to permit a purging of propellant from the combustion chamber in the event of a misfire.

13. The invention defined in claim 1 wherein the drive cam means include a rotatable drive cam member and the control means include a rotatable control cam member.

14. The invention defined in claim 13 including a receiver, guide slots in the receiver, bolt lugs engageable in the guide slots, locking lugs in the barrel and bolt locking means for rotating the bolt lugs into engagement with the locking lugs in the barrel to carry the combustion chamber firing loads through the barrel rather than through the receiver whereby the receiver can be made quite light.

15. The invention defined in claim 13 wherein both the control cam member and the drive cam member are annular, cylindrical members, the control cam member is positioned at the forward end of the drive cam member, the bolt is mounted for reciprocation back and forth within the interior of the drive cam and control cam members, the bolt includes a radially extending cam follower, the drive cam member includes a first internal spiral cam track engageable with the cam follower to drive the bolt forward and a second internal spiral cam track engageable with the cam follower to drive the bolt rearward, the drive cam member includes dwell areas at the front and rear for permitting rotation of the drive cam member without producing axial movement of the bolt and wherein the control cam

member has a rear face formed with an axially projecting bolt return surface engageable with the cam follower to move the cam follower into the second spiral cam track.

16. The invention defined in claim **13** wherein the drive cam means include a bolt locking surface for rotating the bolt to a locked position at the forward, projectile firing position.

17. The invention defined in claim **16** wherein the control cam means include a bolt unlocking surface for rotating the bolt to an unlocked position after the firing of a projectile and prior to the movement of the bolt to the rearward, projectile loading position.

18. The invention defined in claim **13** wherein the gun is a gun module and includes receiver means having an external configuration which permits the gun module to be mounted with other gun modules in patterned groupings to form a modular gun comprising a plurality of individual gun modules and with the receiver means of adjacent gun modules engaged in mutual support.

19. The invention defined in claim **18** wherein the drive means include an idler gear for transferring drive from one gun module to an adjacent gun module so that all of the gun modules in a cluster can be driven from a single drive motor.

20. The invention defined in claim **13** wherein the drive means include gears interconnecting the drive cam member and control cam member for rotation in synchronism.

21. The invention defined in claim **20** wherein both the drive cam member and the control cam member have gears formed on their outer periphery and the drive means include a first gear engageable with the drive cam gear, a second gear engageable with the control cam gear, and an interconnecting drive shaft connected to drive both the first gear and the second gear.

22. The invention defined in claim **21** wherein the control cam member is axially movable into and out of drive engagement with the second gear and including misfire detection means for moving the control cam member out of driving engagement with the second gear in the event of a misfire.

23. The invention defined in claim **22** wherein the misfire detection means include a port through the sidewall of the barrel, a spring biased gas piston mounted for movement against the spring bias by the pressure of combustion gases passing through the port in the barrel, a misfire switch engageable with the control cam member to disengage the control cam member from drive by the second gear, and a connecting rod extending between the gas piston and the misfire switch for retracting the misfire switch to a position in which the misfire switch cannot engage the control cam member when the gas piston is moved against the spring bias.

24. The invention defined in claim **23** including a lug on the control cam member for engagement with the misfire switch.

25. The invention defined in claim **13** wherein the drive cam member and the control cam member are rotatable about axes which are parallel to the axis of reciprocation of the bolt, the bolt includes a cam follower, and the drive cam means include a first spiral cam track engageable with the cam follower to drive the bolt forward and a second spiral cam track engageable with the cam follower to drive the bolt rearward.

26. The invention defined in claim **25** wherein the drive cam means include dwell areas at the front and rear of the drive cam means for permitting rotation of the drive cam means without producing axial movement of the bolt.

27. The invention defined in claim **26** wherein the drive cam means include a hollow cylindrical drive cam member having a longitudinal axis concentric with the axis of reciprocation of the bolt and wherein the bolt is mounted for axial movement within the interior of the drive cam member.

28. The invention defined in claim **27** including biasing means associated with the bolt for biasing the bolt and cam follower forward to cause the cam follower to enter an open end of the first spiral cam track.

29. The invention defined in claim **28** wherein the biasing means include a spring engageable with the rear end of the bolt.

30. The invention defined in claim **29** including sear means for holding the bolt in the rearward position against the force of said spring until the sear is released.

31. The invention defined in claim **27** wherein the cam follower is mounted for sliding movement radially inward and outward of the bolt and including biasing means normally biasing the cam follower radially outwardly of the bolt, a slot in the front dwell having a sidewall engageable with the cam follower for rotating the bolt to a locked position, and receiver cam means for depressing the cam follower radially inwardly of the bolt and out of engagement with said sidewall after the bolt is rotated to the locked position.

32. The invention defined in claim **31** wherein the control means include a hollow annular member having a forward cam face and a rearward cam face, and including an axially projecting surface on a part of the rear cam face for engaging the cam follower to rotate the bolt to an unlocked position and to move the cam follower into the second spiral cam track.

33. The invention defined in claim **32** wherein the drive means are connected to rotate the drive cam member faster than the control cam member and in a direction opposite to the rotation of the control cam member.

34. A modular gun comprising a plurality of gun modules, each of the gun modules having a barrel, a combustion chamber, a receiver, a bolt mounted for axial movement in the receiver between a rearward, projectile loading position and a forward, projectile firing position, liquid propellant injection means for injecting a liquid propellant into the combustion chamber, igniter means for igniting the liquid propellant in the combustion chamber, drive cam means including a rotatable drive cam member for moving the bolt back and forth between the rearward and forward positions, drive means for driving the drive cam means, and control means including a rotatable control cam member controlling the liquid propellant injection means and igniter means in coordination with the drive of the drive cam means, and wherein the receiver means of each gun module have an outer shape which permits a plurality of gun modules to be arranged in patterned groupings with the receiver means of adjacent modules engaged in mutual support.

35. A gun of the kind in which liquid propellant is burned in a combustion chamber to fire a projectile from the gun and comprising,

a gun barrel,

a combustion chamber at one end of the gun barrel,

liquid propellant injection means for injecting a liquid propellant into the combustion chamber,

igniter means for igniting the liquid propellant in the combustion chamber,

liquid coolant injection means for injecting a liquid coolant into the combustion chamber for internally cooling the combustion chamber structure after the firing of each round, and

control means for controlling the timing and amount of liquid coolant injected, said liquid coolant means including a liquid coolant passageway and related ports integral with the barrel and located to inject the liquid coolant into the barrel at the forward end of the combustion chamber so that the liquid coolant is injected into the hottest part of the barrel at a point forward from the rear face of the barrel and the coolant is sprayed both forward and rearward within the barrel.

36. The invention defined in claim **35** wherein the liquid coolant is water.

37. A gun of the kind in which liquid propellant is burned in a combustion chamber to fire a projectile from the gun and comprising,

a gun barrel,

a combustion chamber at one end of the gun barrel,

liquid propellant injection means for injecting a liquid propellant into the combustion chamber,

igniter means for igniting the liquid propellant in the combustion chamber,

liquid coolant injection means for injecting a liquid coolant into the combustion chamber for internally cooling the combustion chamber structure after the firing of each round, and

control means for controlling the timing and amount of the liquid coolant injected and wherein the control means include a rotatable control cam having an outer cam surface, a cam follower rod, biasing means maintaining one end of the cam follower rod engaged with the cam surface, said liquid propellant injection means include a propellant inlet port and a control valve, said liquid coolant injection means include a coolant inlet port and a control valve, and wherein both the propellant control valve and the coolant control valve are connected to the cam follower control rod for coordinating the propellant and coolant injection functions.

38. The invention defined in claim **37** wherein the propellant control valve and the liquid coolant control valve are spool type valves and are mounted for sliding movements within cylindrical bores.

39. The invention defined in claim **38** wherein the propellant control spool valve and the coolant control spool valve are connected to the control rod in a manner such that the coolant control valve blocks the flow of coolant into the combustion chamber while the propellant control valve opens the propellant inlet port for flow of liquid propellant into the combustion chamber and the propellant control valve blocks the flow of propellant into the combustion chamber when the coolant control valve opens the coolant inlet port for the flow of coolant into the combustion chamber.

40. The invention defined in claim **39** including a purge outlet port connected to the cylindrical bore in which the propellant control valve is slidable for permitting the flow of purge liquid out of the propellant inlet and purge outlet port after a misfire of the gun.

41. The invention defined in claim **40** including control cam mounting means mounting the control cam for rotation about an axis extending parallel to the gun barrel and permitting limited axial movement of the control cam, gear drive means engaged with the control cam for rotating the control cam and misfire detection means for shifting the control cam axially to disengage the control cam from the gear drive means after a misfire of the gun.

42. The invention defined in claim **41** wherein shifting of the control cam to disengage the control cam from the gear drive means moves the cam follower control rod to shift the coolant inlet control valve and the propellant control valve to positions in which the coolant flows through the coolant inlet port and out the propellant inlet port and purge outlet port to thereby fill the combustion chamber with coolant liquid and to purge the combustion chamber of all propellant.

43. A gun of the kind in which liquid propellant is burned in a combustion chamber to fire a projectile from the gun and comprising,

a gun barrel,

a combustion chamber at one end of the gun barrel,

liquid propellant injection means for injecting a liquid propellant into the combustion chamber,

igniter means for igniting the liquid propellant in the combustion chamber,

liquid coolant injection means for injecting a liquid coolant into the combustion chamber for internally cooling the combustion chamber structure after the firing of each round, and

control means for controlling the timing and amount of the liquid coolant injected, and wherein the liquid propellant injection means and liquid coolant injection means are operatively associated with the control means for positioning the propellant injection means and coolant injection means in a first position in which the flow of both liquid propellant and liquid coolant into and out of the combustion chamber is blocked during firing of the gun, in a second position in which the flow of liquid propellant is permitted into the combustion chamber and the flow of liquid coolant into the combustion chamber is blocked during propellant injection prior to firing, and a third position in which the flow of liquid propellant into the combustion chamber is blocked while the flow of liquid coolant into the combustion chamber is permitted for cooling and purging of the combustion chamber.

* * * * *

ADDENDUM A

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SLURRIED GUN PROPELLANTS
State-of-the-Art Patent
Study (BDM/M-tpg-0083-81)

Dear Terry:

Thank you for writing February 19, 1981, and enclosing an outline disclosure of the BDM proposal for researching liquid monopropellants, and particularly high energy slurry formats for gun systems. We have now completed a state-of-the art patent search, as reported to you by telephone on March 25, 1981, and enclose our selection of relevent patent literature to assist you in developing a library on this subject matter.

In summary, we approached this assignment with an emphasis upon slurry compositions, but with an eye out for any fluid propellant teaching for guns, generally. Accordingly, our field of search necessarily covered areas which apparently were not pertinent to slurry propellant but might incidentally relate to gun propellants. To assist future users of this assembly of

patent teachings, we additionally enclose a computer listing of all patents within certain selected Classes and Subclasses as defined by the United States Patent Office classification system.

Our field of search comprised Class 60, Subclasses 214, 216, 217, 252; Class 89, Subclass 7; Class 102, Subclass 38CC, 38LP, 202; and Class 149, Subclass 38, 47, 92. Copies of the Class schedules for each of Classes 60, 89, 102 and 149 are also enclosed for your reference. For your possible further reference, we enclose a computer printout of all patents which have been classified within Class 60/217, 252; Class 89/7; Class 102/89, 202 and Class 149/36, 47, 92 and 118. Please note that with respect to Class 102/38, there is no official listing of patents within the supersubclasses 38CC, 38LP, hence, that listing has been so noted.

With respect to high energy slurries and gels, the enclosed patents have been selected primarily due to a suggestion that a given composition had a known utility with respect to some form of gun propellant. Should BDM specifically be interested in any given composition of matter, we would then necessarily focus a search upon that chemical compound. The enclosed patents comprise a survey of teachings for compounds emphasized to have utility as gun propellants, and state-of-the-art surveys are primarily useful to allow researchers to avoid re-inventing the

wheel. We stand ready to perform a detailed patentability study on a given compound and render a patentability opinion as any specific candidates arise.

The attached copies have been selected from various locations within the above-noted field of search and are here listed chronologically, for your convenience:

RYKER	2,970,899
TURNER	3,175,494
GOULD	3,254,603
NEWMAN et al.	3,520,137
DEHM et al.	3,676,533
DORSEY et al.	3,749,615
ASHLEY	3,783,737
HENDERSON	3,811,970
QUINLAN et al.	3,847,081
ALLAN	3,857,743
BRIDGEFORTH et al.	3,861,138
BRABETS et al.	3,901,153
FORREST	3,912,560
DUNETZ	3,913,488
ELMORE et al.	3,916,792
TANNENBAUM	3,921,394
COX et al.	3,925,125
TEZUKA	3,956,040
SCHNEIDER et al.	3,969,979
RIDGEWAY	3,980,510
MICKELSON	3,980,552
WOOD	4,004,415
HOLTROP	4,005,632
ASHLEY	4,011,817
BRUNNBERG	4,014,655
GAWLICK et al.	4,014,963
TASSIE	4,023,463
LENEVEU	4,023,996
HOLTROP	4,033,224
ALLAN	4,039,360
BULMAN et al.	4,043,248
GRAHAM	4,050,348
GRAHAM	4,050,349

TASSIE	4,050,352
ASHLEY	4,051,762
ELMORE et al.	4,062,266
ASHLEY	4,063,486
ASHLEY	4,069,739
TASSIE et al.	4,085,653
OUTTEN	4,090,895
PETERSEN et al.	4,091,711
BRESLOW	4,094,713
MULLAY	4,097,316
SINGELMANN et al.	4,099,445
HOFFMANN	4,100,836
ASHLEY	4,102,269
HERSHKOWITZ et al.	4,110,136
JUNKER	4,123,963
ASHLEY	4,126,078
ASHLEY	4,132,149
FORREST	4,132,574
CAMERON et al.	4,141,766
STEFFANUS et al.	4,148,245
AYLER et al.	4,160,405
GROEN et al.	4,161,904
ELMORE et al.	4,164,889
ELMORE et al.	4,164,890
PETERSON et al.	4,170,922
AYLER et al.	4,172,408
REED, JR., et al.	4,180,424
FLANAGAN et al.	4,187,781
TASSIE	4,193,335
TASSIE et al.	4,215,620
PIERCE	4,216,039
McLEAN	4,221,616
COOK	4,221,618
ASHLEY	4,231,282
REED, JR., et al.	4,239,073

We trust the enclosed patent copies, copies of the Patent Office class definitions, and also the computer listing of patents in several selected subclasses, will be of immediate value to the reference library being assembled by the BDM researchers.

We stand ready to review the patentability question for specific candidates, as such are generated.

Best regards.

Sincerely,

Warren

Warren E. Olsen

WEO:rmo

Enclosures:

1) Listed Patents
2) Computer printout